Technical Report 1702
November 1995

SeaRad, A Sea Radiance Prediction Code

C. R. Zeisse

Naval Command, Control and
Ocean Surveillance Center
RDT&E Division

San Diego, CA
92152-5001

Technical Report 1702
November 1995

SeaRad, A Sea Radiance Prediction Code

C. R. Zeisse

NAVAL COMMAND, CONTROL AND OCEAN SURVEILLANCE CENTER
RDT&E DIVISION
San Diego, California 92152-5001

K. E. EVANS, CAPT, USN
Commanding Officer

R. T. SHEARER
Executive Director

ADMINISTRATIVE INFORMATION

The work detailed in this report was performed for the Office of Naval Research by the Naval Command, Control and Ocean Surveillance Center, RDT&E Division, Tropospheric Branch, Code 543. Funding was provided under Program Element 0602435N, Accession Number DN302215.

Released by
R. A. Paulus, Head
Tropospheric Branch

Under authority of
J. H. Richter, Head
Ocean and Atmospheric Sciences Division

SB

EXECUTIVE SUMMARY

OBJECTIVE

Develop a computer code to predict sea radiance (brightness).

APPROACH

Sea radiance is modeled by combining the methods of geometrical optics with the Cox-Munk statistical description of ocean capillary waves. The model is incorporated into the atmospheric transmittance/radiance code MODTRAN2 to provide numerical sea radiance predictions.

In this model each individual capillary wave facet is allowed to reflect the sky or sun and emit thermal radiation. The total radiance from the sea is obtained by applying the proper statistical weight to each facet and integrating over all facets within the observer's field-of-view.

RESULTS

The modified MODTRAN2 code, called *SeaRad*, calculates sea radiance for any viewing geometry in a spectral range from 52.63 cm^{-1} to 25000 cm^{-1}. Typical execution speeds are approximately 10 s per pixel on a Pentium/90 MHz personal computer. Preliminary comparisons show that *SeaRad* agrees to within several degrees Celsius (°C) with actual sea radiance measurements in the mid-wave and long-wave infrared bands.

CONTENTS

Figures

1. INTRODUCTION

SeaRad is a FORTRAN computer code that predicts the radiance (brightness) of the ocean surface. *SeaRad* is based on the Cox-Munk statistical model (Cox and Munk, 1954, 1956) for wind-driven capillary wave facets. An individual facet is chosen and assigned a specific slope with respect to the local horizon. The facet is allowed to reflect the sky and sun and emit thermal black body radiation toward an observer. The total radiance is obtained by applying the proper statistical weight to the facet and integrating over all facets within the observer's field-of-view.

SeaRad is valid for a spectral range extending from the visible to the far infrared. Preliminary comparisons show that *SeaRad* agrees to within several °C with actual sea radiance measurements in the mid-wave and long-wave infrared bands.

In its current form, *SeaRad* is a self-contained, DOS-compatible program that runs on a personal computer and computes radiance for a single pixel (rather than an entire image). It is a modified version of the Air Force program MODTRAN2 (Berk, et al., 1989; Kneizys, et al., 1988) that computes atmospheric transmittance and radiance. *SeaRad* operates exactly like the original MODTRAN2 code[1] except that a new logical parameter, "SeaSwitch", is required in the input file. Sun glint is included in the sea radiance prediction provided that the user has chosen to execute *SeaRad* in radiance mode with solar scattered radiance included (IEMSCT = 2).

2. HARDWARE CONSIDERATIONS

The size of the FORTRAN source code is 1.8 MB. When assembled by version 5.01 of the Lahey F77L/EM-32 DOS compiler, the size of the executable code is 0.8 MB. When run[2] on a Pentium/90 at low spectral resolution (LOWTRAN7) in multiple scattering mode, execution times are 4 s for a typical thermal long-wave case (830 to 1250 cm^{-1} in 21 spectral steps) and 17 s for a typical solar mid-wave case (2000 to 3340 cm^{-1} in 67 spectral steps). Source and executable codes are available on disk through correspondence with the author.

3. AN EXAMPLE

This section provides an example of how *SeaRad* is used to predict radiance of the ocean surface. An input file called "Tape5Rad.Std," shown on page A-2, employs a 1976 U. S. standard atmosphere to calculate ocean radiance observed at a zenith angle of 100° (a depression angle of 10°) from a height of 23 m. The Navy aerosol model is used. The calculation is done at low spectral resolution (LOWTRAN7) for a single wave number (945 cm^{-1}) in the long-wave band.

With this file present, the following three DOS commands will calculate ocean radiance and display results:

```
Copy    Tape5Rad.Std    Tape5
SeaRad
Type Out
```

1. This report assumes that the reader is familiar with MODTRAN2 operation.
2. The compiler requires the Lahey/Phar Lap 386 DOS Extender program (0.2 MB) to run on a personal computer.

These commands[3] produce the output file "Out" (Appendix A, page 3). Band-integrated radiance values in W m^{-2} sr^{-1} are listed at the end of the output file for each of four contributions to ocean radiance: path to footprint, sea emission, sky reflection, and sun glint. (In fact, no sun glint has been calculated in this instance since the input file specifies IEMSCT = 1 rather than IEMSCT = 2.) Please note that the parameter "TBOUND" in the input file has been reinterpreted by *SeaRad* as the sea temperature.

The input file shown in Appendix A on page 2 contains two new parameters at the end of the third line: "90.000" and "T". These will be discussed in reverse order of their appearance.

The "T", which may appear anywhere in columns 76 through 80 of the third line of the input file (at the end of Card 3), is a new logical parameter "SeaSwitch". It is required; that is, a fatal error will be generated if it is not present in the input file. "SeaSwitch" controls the sea radiance calculation. When "SeaSwitch" is equal to "T", the sea radiance calculation will be allowed provided certain other conditions are met. When "SeaSwitch" is equal to "F", the sea radiance calculation will be prevented under all conditions and the program will execute as originally released by the Air Force.

The "90.000", which may appear anywhere in columns 66 through 75 of the third line of the input file (near the end of Card 3), is a new floating point parameter, "Psi". It is optional; that is, the program will run whether this parameter is included in the input file or not. "Psi" is the azimuth of the upwind direction[4] measured from the line-of-sight in degrees positive East of North. If it is omitted (if the field is blank), and if all conditions for a sea radiance calculation are met, that calculation will proceed under the assumption that the value of "Psi" is zero, meaning that the observer is looking directly into the wind. For the input file in Appendix A, "Psi" is 90°, meaning that the wind is blowing from right to left, perpendicular to the direction of observation.

The modified version of Card 3 used by SeaRad is:

H1, H2, ANGLE, RANGE, BETA, R0, LEN, Psi, SeaSwitch
Format (6F10.3, I5, F10.3, L5)

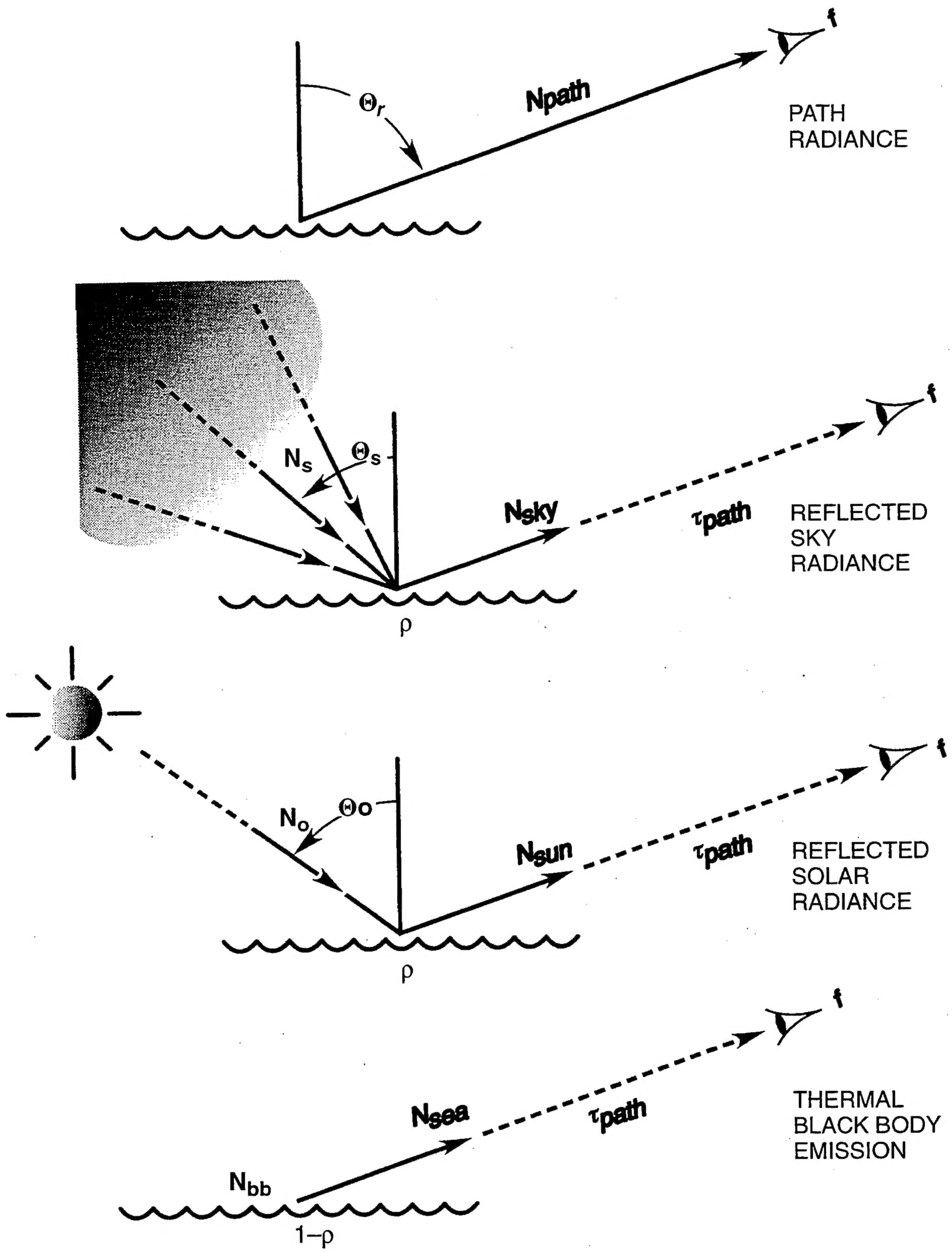
4. THE MODEL

The primary assumption of the model is that the strength of interaction between an optical ray and a capillary wave facet is given by the facet area projected normal to the ray. A feature (Zeisse, 1994. 1995) of the equations contained in *SeaRad* is that they predict a finite horizon radiance. *SeaRad* does not include multiple reflections, shadowing, or gravity waves. Polarization is ignored.

The model computes four contributions to sea radiance. Each of the four contributions is shown in figure 1. (For purposes of clarity, only two dimensions have been used in figure 1; however, all three dimensions are used in the actual calculation.)

The first contribution is path radiance, shown at the top of figure 1. The footprint of a single pixel in an image of the sea is indicated by the wavy line. The footprint is observed by a receiver at the end

3. The time for this particular test case was 3 s on a 486/50 MHz personal computer.
4. This information is required because the Cox-Munk capillary wave slope statistics are different in the upwind and crosswind directions.



$$\left(N_{sky} + N_{sun} + N_{sea}\right) \tau_{path} \cdot f + N_{path} \cdot f = N$$

Figure 1. Four contributions to sea radiance.

of a ray whose zenith angle at the footprint is θ_r. Let N_{path} designate the spectral radiance in W m^{-2} sr^{-1} (cm^{-1})$^{-1}$ along the path[5] from the footprint to the receiver.

The second contribution is reflected sky radiance. Spectral radiance N_s from a portion of the sky arrives at the footprint along a ray whose zenith angle there is θ_s. The footprint contains wave facets of different slopes, many that reflect the incoming sky radiance away from the receiver toward other parts of the sky. These facets are ignored. However, the footprint will contain some facets whose slope is correct for reflecting the incoming sky radiance toward the receiver along the path defined by the zenith angle θ_r. These facets are retained. The contributions from all portions of the sky are summed together after specular reflection by the appropriate facets within the footprint, and the sum leaving the footprint at zenith angle θ_r is designated N_{sky}. During its path to the receiver, the reflected sky radiance is attenuated by the path transmission τ_{path}.

The third contribution is reflected solar radiance, sun glint. The calculation is analogous to the calculation of sky radiance. Spectral radiance N_o from the solar center arrives at the footprint along a path whose zenith angle there is θ_o. Within the footprint, most facets deflect the solar ray away from the receiver and are rejected, but some facets are retained because they deflect the ray specularly toward the receiver along a path with zenith angle θ_r. N_{sun} is the spectral radiance leaving the footprint after summation over rays arriving from all portions of the solar disk. The reflected solar radiance is also attenuated by the path transmission τ_{path} before final reception.

The fourth contribution is thermal black body emission. Each facet emits a spectral radiance N_{bb} given by Planck's equation for a black body whose temperature is equal to the value of "TBOUND" in the input file. The spectral emissivity of a given facet in the direction of the receiver is specified by the slope of that facet and the value of θ_r. N_{sea} is the thermal spectral radiance leaving the footprint for the receiver after summation over all facets within the footprint. As before, N_{sea} is attenuated by path transmission after leaving the footprint.

Throughout figure 1, the symbol ρ represents the spectral reflectivity of sea water, which is required for the second and third contributions since they are governed by the process of optical reflection. On the other hand, the fourth contribution is governed by the process of optical emission. Fortunately, by application of Kirchoff's Law to an opaque medium, sea water, the emissivity is given by one minus the reflectivity. The reflectivity is calculated from Fresnel's equations (Stratton, 1941) with a complex optical index taken from the literature (Hale & Querry, 1973; Querry, et al., 1977). These data for the index, available between 52.63 cm^{-1} and 25000 cm^{-1}, set the spectral range of *SeaRad.*

The total spectral radiance N received at wave number ν (cm^{-1}) is given by

$$N(\nu) = N_{path}(\nu)\, f(\nu) + \left[N_{sky}(\nu) + N_{sun}(\nu) + N_{sea}(\nu)\right] \tau_{path}(\nu)\, f(\nu)\,, \tag{1}$$

where $f(\nu)$ has been introduced to represent the spectral responsivity of the receiver.

The design of *SeaRad* is such that path (N_{path}, τ_{path},) and source (N_s, N_o, N_{bb}) values are taken from the original MODTRAN2 while Fresnel reflection (ρ) and slope integrated values (N_{sky}, N_{sun}, N_{sea}) are introduced in new subroutines. Integration of (1) over the wave number band specified in the input file is carried out in a modification of subroutine "TRANS" to produce the band-integrated values for sea radiance given in the output file.

5. In this report, the word path refers to only the optical path between the footprint and the receiver.

5. THE COORDINATE SYSTEM

The previous description neglected the azimuthal dependence of rays arriving and leaving the footprint. The full three-dimensional geometry will now be introduced.

Figure 2 shows the geometry of reflection. A coordinate system was chosen whose origin is the point of reflection with the *X*-axis pointing upwind, the *Z*-axis pointing toward the zenith, and the *Y*-axis pointing crosswind such that a right-handed system is formed. The *X*-*Y* plane is horizontal at the point of reflection. The tilted facet passes through the origin.

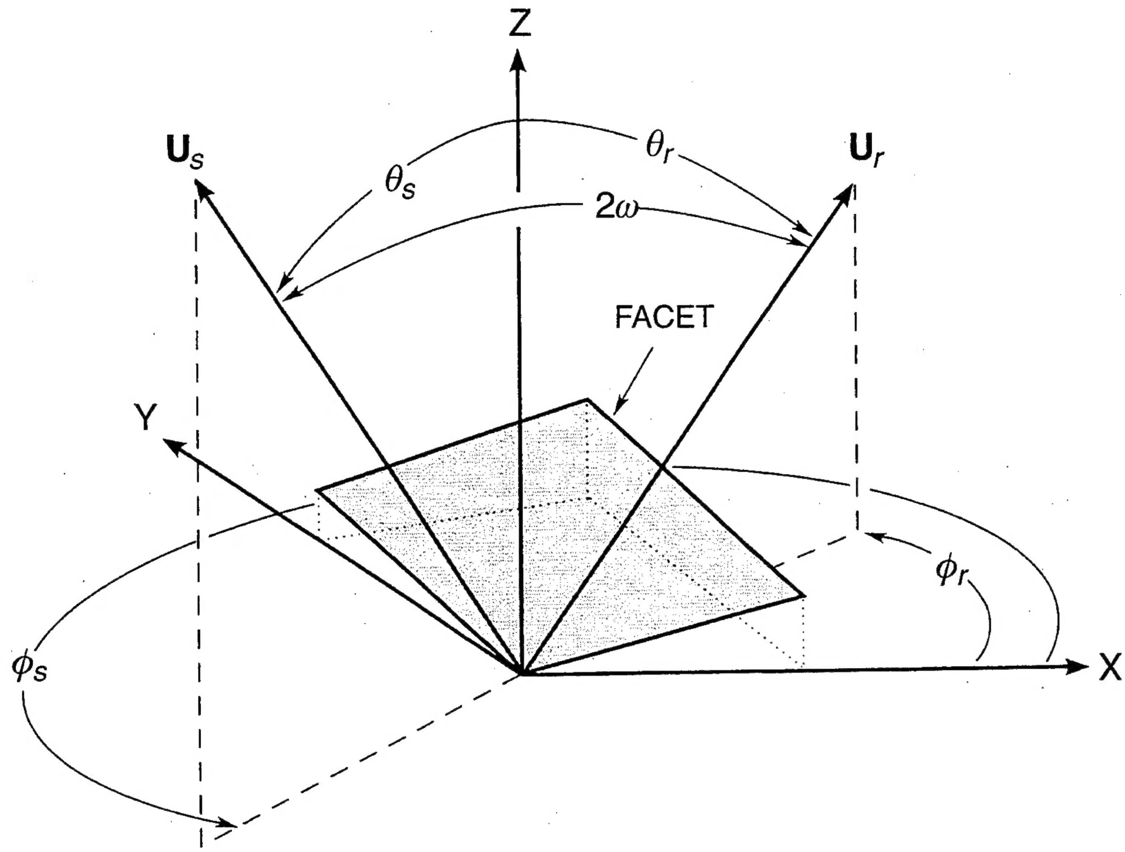


Figure 2. Coordinate system for facet reflection.

Define a unit vector $\mathbf{U} \equiv (\theta, \phi)$ with polar coordinates θ, the zenith angle, and ϕ, the azimuth. If we denote the Cartesian coordinates of $\mathbf{U}$ by (a, b, c), then we have

$$\begin{aligned} a &= \sin\theta\cos\phi \\ b &= \sin\theta\sin\phi \\ c &= \cos\theta \end{aligned} \tag{2}$$

for the Cartesian coordinates of $\mathbf{U}$ in terms of its spherical coordinates and

$$\begin{aligned} \theta &= \cos^{-1}(c) \\ \phi &= \tan^{-1}(b/a) \end{aligned} \tag{3}$$

for the spherical coordinates of **U** in terms of its Cartesian coordinates. Two unit vectors are shown in figure 2: $\mathbf{U}_s$, pointing from the origin to the source, and $\mathbf{U}_r$, pointing from the origin to the receiver. A third unit vector, $\mathbf{U}_n$, is normal to the facet at the point of reflection but was removed from the figure for clarity[6].

The facet slope in the upwind direction, ζ_x, is given by the slope of the line formed at the intersection of the facet with the *X-Z* plane. The facet slope in the crosswind direction, ζ_y, is given by the slope of the line formed at the intersection of the facet with the *Y-Z* plane. In terms of the Cartesian coordinates of the facet normal these slopes are

$$\begin{aligned} \zeta_x &= -\, a_n/c_n \\ \zeta_y &= -\, b_n/c_n \end{aligned} \tag{4}$$

6. SPECULAR REFLECTION

If a specular reflection occurs, the three vectors for source, receiver, and facet normal are connected by the law of reflection:

$$\mathbf{U}_s + \mathbf{U}_r = 2\cos\omega\ \mathbf{U}_n \tag{5}$$

where ω is the angle of incidence and the angle of reflection.

7. THE OCCURRENCE PROBABILITY

Following Cox and Munk, let P stand for the probability

$$P \equiv p(\zeta_x, \zeta_y, W)\ d\zeta_x\, d\zeta_y \tag{6}$$

that a wave facet will occur with a slope within $\pm\, d\zeta_x/2$ of ζ_x and $\pm\, d\zeta_y/2$ of ζ_y when the wind speed is W. The wave slope occurrence probability density, p, is proportional to the horizontal projection of the facet. Cox and Munk obtained an expression for p whose lowest order term is

$$\begin{aligned} p(\zeta_z, \zeta_y, W) &\approx \frac{1}{2\pi\sigma_u\sigma_c} \exp\left\{ -\frac{1}{2}\left(\frac{\zeta_x^2}{\sigma_u^2} + \frac{\zeta_y^2}{\sigma_c^2}\right)\right\} \\ \sigma_u^2 &= 0.000 + 3.16 \cdot 10^{-3} W \\ \sigma_c^2 &= 0.003 + 1.92 \cdot 10^{-3} W \end{aligned} \tag{7}$$

Here σ_u^2 and σ_c^2 are the variances in ζ_x and ζ_y respectively and W is the wind speed in m s^{-1}. Figure 3 shows the dependence of p throughout slope space for a wind speed of 10 m s^{-1}. The coordinate system of figure 2 has been inserted at the top of the figure to illustrate the relation between coordinates and slopes. Note that the first *X-Y* quadrant corresponds to negative slopes.

6. The zenith angle of $\mathbf{U}_n$ is the same as the tilt of the facet. The tilt is the angle of the steepest ascent within the facet.

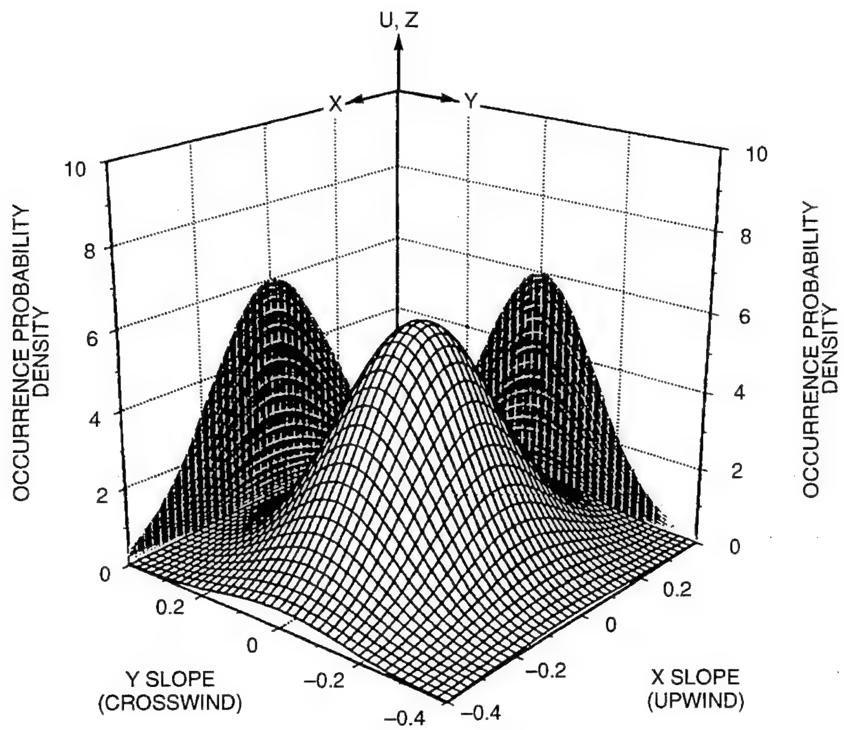


Figure 3. Cox-Munk occurrence probability density for a windspeed of 10 m s^{-1}.

8. THE INTERACTION PROBABILITY

Following a suggestion of Plass, et al. (1976), let Q stand for the (different) probability

$$Q \equiv q(\zeta_x, \zeta_y, \theta, \phi, W)\ \zeta_x\ d\zeta_y \tag{8}$$

that a facet whose slope is within $\pm d\zeta_x/2$ of ζ_x and $\pm d\zeta_y/2$ of ζ_y will interact with a ray arriving from the arbitrary direction $\mathbf{U} = (\theta, \phi)$ when the wind speed is W. The wave slope interaction probability density, q, is proportional to the facet area projected normal to the ray. It has previously been shown (Zeisse, 1994, 1995)[7] that

$$q(\zeta_x, \zeta_y, \theta, \phi, W) = \frac{\dfrac{\cos\omega}{\cos\theta_n} p}{\displaystyle\iint_{\substack{\omega \le \pi/2 \\ U = const.}} \frac{\cos\omega}{\cos\theta_n} p\ d\zeta_x\ d\zeta_y} \tag{9}$$

Figure 4 is a graph of equation (9), also for a wind speed of 10 m s^{-1}, showing how facets with a specified slope interact with a ray pointing in the direction (80°, 270°).

7. Equation (9) is only defined for $\omega \le \frac{\pi}{2}$.

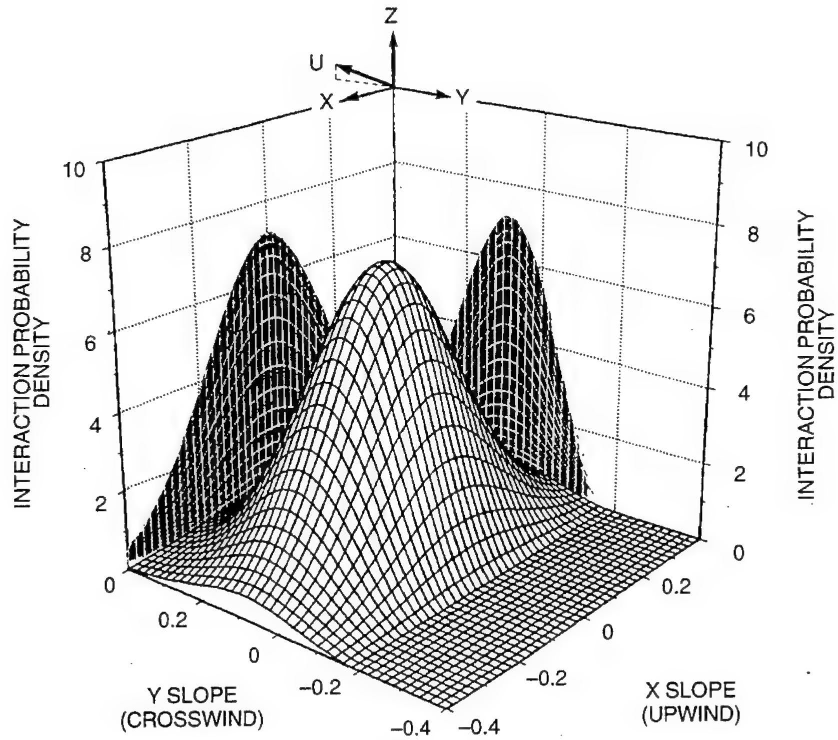


Figure 4. Cox-Munk-Plass interaction probability density for a windspeed of 10 m s^{-1}.

9. EQUATIONS FOR SEA RADIANCE

The capillary wave contributions to sea radiance are

$$N_{sky}(\theta_r, \phi_r, W, \nu) = \iint\limits_{\substack{\theta_s, \omega \le \pi/2 \\ U_r = const.}} N_s(\theta_s, \phi_s, \nu)\rho(\omega, \nu) q\left(\zeta_x, \zeta_y, \theta_r, \phi_r, W\right) \, d\zeta_x \, d\zeta_y \tag{10}$$

$$N_{sun}(\theta_o, \phi_o, \theta_r, \phi_r, W, \nu) \approx \frac{N_o(\theta_o, \phi_o, \nu)}{4} \cdot \tag{11}$$

$$\iint\limits_{\substack{disk \\ U_r = \text{const.}}} \rho\,(\omega, \nu)\ \sec\omega\ sec^3\theta_n\ q(\zeta_x, \zeta_y, \theta_r, \phi_r, W)\ sin\theta_s\ d\theta_s\ d\phi_s$$

$$N_{sea}(\theta_r, \phi_r, W, T_{sea}, \nu) = N_{bb}\left(T_{sea}, \nu\right) \iint\limits_{\substack{\omega \le \pi/2 \\ U_r = const.}} \left[1 - \rho(\omega, \nu)\right] q\left(\zeta_x, \zeta_y, \theta_r, \phi_r, W\right) \, d\zeta_x \, d\zeta_y \tag{12}$$

In each of the integrals (10) through (12), q plays the role of a weighting function attached to the facet. The weight is applied to the ray leaving the footprint and propagating toward the receiver, and

that ray and those receiver coordinates are held constant in all of the integrals. A physical description and some mathematical details of each equation will now be presented.

In the integrand of (10), the product of N_s and ρ represents the radiance leaving a single facet when $N_s(\theta_s, \phi_s, \nu)$ is the spectral sky radiance incident on that facet at zenith angle θ_s and azimuth ϕ_s. This product is weighted by q and integrated over all slopes in the ocean. During integration, a specular reflection occurs at one facet after another inside the footprint with the outgoing (receiver) ray held fixed. The source ray is swept across the sky and sun. Equation (10) will require explicit expressions for each of its variables in terms of slopes and receiver coordinates. From (2) and (4) it can be shown that the facet tilt is given in terms of the facet slopes by

$$\cos\theta_n = c_n = \frac{1}{\sqrt{1 + \zeta_x^2 + \zeta_y^2}} \tag{13}$$

while the fact that ω is the the angle between the facet normal and the receiver ray implies that

$$\begin{aligned} \cos\omega &= \mathbf{U}_n \cdot \mathbf{U}_r \\ &= a_n a_r + b_n b_r + c_n c_r \\ &= \left\{- \zeta_x a_r - \zeta_y b_r + c_r\right\} c_n \\ &= \frac{\left\{- \zeta_x \sin\theta_r \cos\phi_r - \zeta_y \sin\theta_r \sin\phi_r + \cos\theta_r\right\}}{\sqrt{1 + \zeta_x^2 + \zeta_y^2}} \end{aligned} \tag{14}$$

Equations (13) and (14) hold at all times, regardless of whether a specular reflection is taking place. When a specular reflection does occur, the Z component of the law of reflection

$$\mathbf{U}_s = 2 \cos\omega \; \mathbf{U}_n - \mathbf{U}_r \tag{15}$$

gives

$$\begin{aligned} \cos\theta_s &= 2 \cos\omega \; c_n - c_r \\ &= \frac{2\{ \ \} - c_r/c_n^2}{1/c_n^2} \\ &= \frac{-2 \sin\theta_r \left(\zeta_x \cos\phi_r + \zeta_y \sin\phi_r\right) + \cos\theta_r \left(1 - \zeta_x^2 - \zeta_y^2\right)}{1 + \zeta_x^2 + \zeta_y^2} \end{aligned} \tag{16}$$

where { } represents the expression within curly braces in (14). Finally, the X and Y components of (15) give

$$\begin{aligned} \tan\phi_s &= \frac{b_s}{a_s} \\ &= \frac{2 \cos\omega \; b_n - b_r}{2 \cos\omega \; a_n - a_r} \\ &= \frac{2\zeta_y\left\{ \ \right\} + b_r/c_n^2}{2\zeta_y\left\{ \ \right\} + a_r/c_n^2} \\ &= \frac{\left(1 + \zeta_x^2 - \zeta_y^2\right) \sin\phi_r - \left(2\zeta_x\zeta_y\right) \cos\phi_r + \left(2\zeta_y\right) \cot\theta_r}{\left(1 - \zeta_x^2 + \zeta_y^2\right) \cos\phi_r - \left(2\zeta_x\zeta_y\right) \sin\phi_r + \left(2\zeta_x\right) \cot\theta_r} \end{aligned} \tag{17}$$

for the source azimuth during specular reflection by a facet $\left(\zeta_x, \zeta_y\right)$ into a receiver at $(\theta_r, \ \phi_r)$.

Equations (13), (14), (16), and (17) should be used in (10) [and in equation(9) when using (10)]. The Cartesian expressions are convenient for computer calculation while the spherical expressions are consistent with the form of equations (10) through (12).

In the integrand of (11), the product of N_o and ρ represents the spectral radiance leaving a single facet when $N_o(\theta_o, \phi_o, \nu)$ is the spectral radiance arriving at that facet from the sun whose center is at (θ_o, ϕ_o). The remaining factors in (11), apart from q, are the Jacobian of the transformation from ocean slopes to sky coordinates (Zeisse, 1994). As before, the integrand is weighted by q but now the integration is over the solar disk in the sky. (It is assumed in (11) that $N_o(\theta_o, \phi_o, \nu)$ does not vary during integration because the sun is a Lambertian source and the solar disk is small.) During integration, a specular reflection from the sun to the receiver occurs at those facets within the footprint with the correct slope. Explicit expressions for each of the variables in terms of source and receiver coordinates will be required in (11). The law of reflection

$$2 \cos \omega \ \mathbf{U}_n = \mathbf{U}_s + \mathbf{U}_r \tag{18}$$

gives the facet position in terms of the source and receiver positions whenever a specular reflection occurs. The components of (18) give

$$\begin{aligned} \zeta_x &= -\frac{a_n}{c_n} \\ &= -\frac{a_s + a_r}{c_s + c_r} \\ &= -\frac{\sin\theta_s \ \cos\phi_s + \sin\theta_r \ \cos\phi_r}{\cos\theta_s + \cos\theta_r} \end{aligned} \tag{19}$$

and

$$\begin{aligned} \zeta_y &= -\frac{b_n}{c_n} \\ &= -\frac{b_s + b_r}{c_s + c_r} \\ &= -\frac{\sin\theta_s \ \sin\phi_s + \sin\theta_r \ \sin\phi_r}{\cos\theta_s + \cos\theta_r} \end{aligned} \tag{20}$$

while its square gives

$$\begin{aligned} 2 \cos^2\omega &= 1 + \boldsymbol{U}_s \cdot \boldsymbol{U}_r \\ &= 1 + a_s \ a_r + b_s \ b_r + c_s \ c_r \\ &= 1 + \sin\theta_s \sin\theta_r \cos(\phi_s - \phi_r) + \cos\theta_s \cos\theta_r \end{aligned} \tag{21}$$

Finally, from (2), (4), and (18) we have

$$
\begin{aligned}
\tan^2\theta_n &= \zeta_x^2 + \zeta_y^2 \\
&= \frac{(a_s + a_r)^2 + (b_s + b_r)^2}{(c_s + c_r)^2} \\
&= \frac{\sin^2\theta_s + \sin^2\theta_r + 2\sin\theta_s \sin\theta_r \cos(\phi_s - \phi_r)}{(\cos\theta_s + \cos\theta_r)^2}
\end{aligned}
\tag{22}
$$

Expressions (19) through (22) should be used in (11) [and in (9) when using(11)]. They apply only when there is a specular reflection.

In (12) there is no incident ray or specular reflection, and integration is over all slopes in the ocean. The integral in (12) is the effective spectral emissivity of the ocean. Explicit expressions in terms of slopes and receiver coordinates will also be required for each of the variables in (12) [and in (9) when using (12)]. Equation (13) is the expression for θ_n and equation (14) is the expression for ω.

10. *SEARAD*

SeaRad consists of new routines added to MODTRAN2 to compute the spectral values of N_{sky}, N_{sun}, and N_{sea} according to equations (10), (11), and (12), respectively. Through modifications to subroutine "TRANS", these values are assembled according to (1) and integrated over the wave number after obtaining proper path radiance and transmittance spectral values. *SeaRad* also introduces minor changes in subroutine "DPFNMN" and major changes in subroutine "DRIVER". These changes will now be considered in more detail.

The modifications to "DRIVER" are briefly shown in figure 5. After the normal call to "GEO", a test is conducted to see whether the ray chosen by the user has hit the surface of the sea. If so, geometry cards required for the sea calculation are issued by subroutine "Card" to file "Tape5.Sea", and input is temporarily redirected to "Tape5.Sea". An example of "Tape5.Sea" is given on page A-4, for the run initiated by the input file on page A-2. After the final card has been read from "Tape5.Sea", sea radiance is calculated in "TRANS". Then "TAPE5" is restored as the active input file and normal program execution is resumed. Please see Appendix B for a detailed flowchart of the modifications to "DRIVER" as well as the complete source code for the modified version of "DRIVER".

Conditions in "DPFNMN" determine whether or not the sea has been hit. "DPFNMN" is a subroutine reached by a sequence of calls beginning in the driver with a call to subroutine "GEO". Modifications to "DPFNMN" are summarized in figure 6. A logical variable "Sea", initially set false, is set true in "DPFNMN" if the following four conditions are met:

1. The program has reached the section of code following the comment line "Tangent path intersects earth."
2. The user has chosen a radiance mode.
3. The variable "HMIN" is equal to zero.
4. The variable "SeaSwitch" is true.

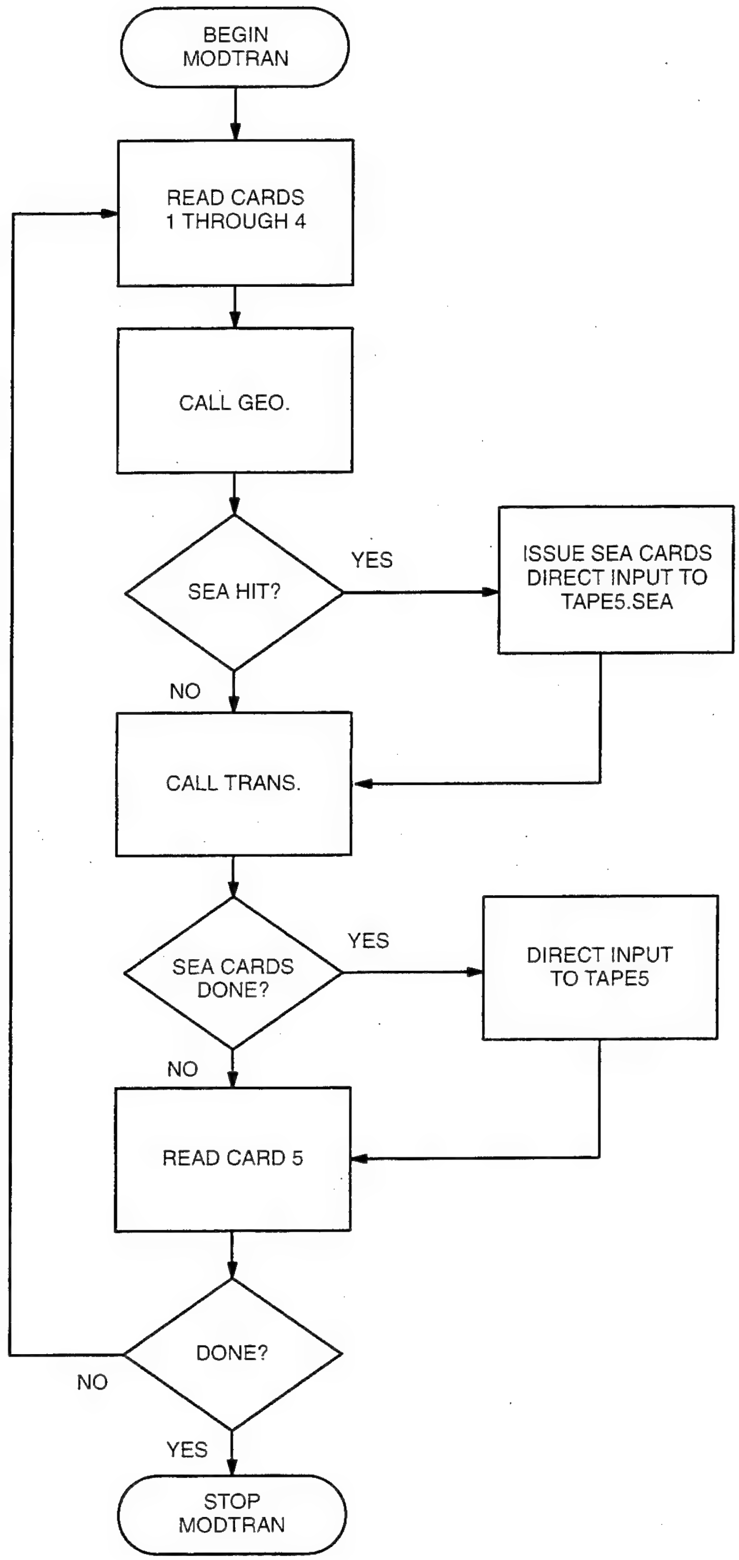


Figure 5. Flowchart for modifications to MODTRAN2 subroutine “DRIVER.”

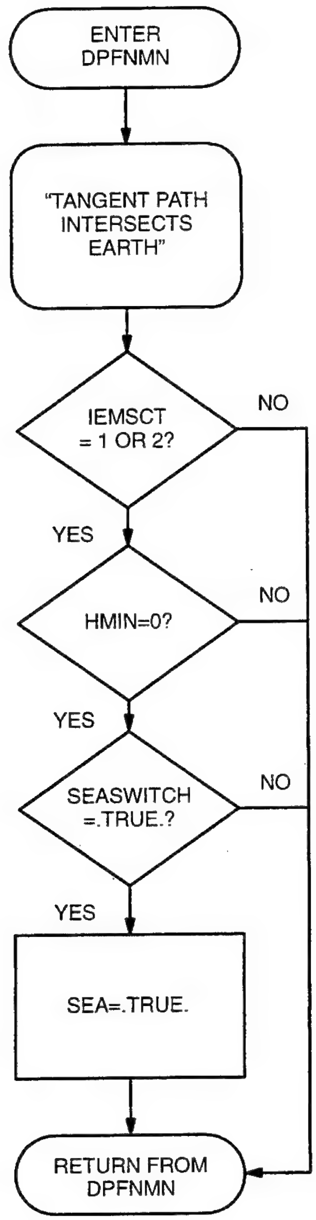


Figure 6. Flowchart for modifications to MODTRAN2 subroutine "DPFNMN."

The variable "Sea" is stored in a common block made available to the driver, which inspects "Sea" before and after each of its calls to "GEO". A change from false to true indicates that the ocean has been hit during that call. A hit induces a geometry calculation by a call to subroutine "Foot" (if IEMSCT = 1) or subroutine "SunFoot" (if IEMSCT = 2). This is followed in each case by a call to subroutine "Card".

The purpose of "Card" is to supply sources for the Cox-Munk routines "Sky" and "Sun." As shown in figure 7, geometry cards are issued here to file "Tape5.Sea" to obtain spectral radiance along paths to the sky at three separate zenith angles. These three cards, one for each zenith angle, are called "Sky Cards" in the flowchart. Later these data will be used by subroutine "Fit" to establish a two-parameter least squares fit at each wave number providing "Sky" with the sky dome radiance.

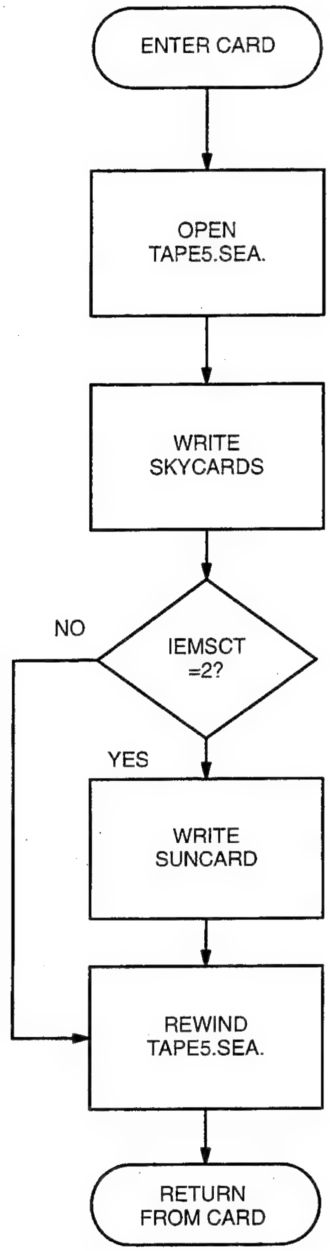


Figure 7. Flowchart for SeaRad subroutine "Card."

If the sun is involved, “Card” will issue a fourth and final Card 3, called a “Sun Card” in the flow-chart, which provides solar irradiance for later use as a source by subroutine “Sun”.

The modifications described to this point have, in effect, inserted three sky cards (followed by a sun card if necessary) into the user’s input file without the user’s knowledge. The insertion is made only if the user has chosen a Card 3 whose path terminates on the surface of the earth. Such a Card 3 is called a “Path Card” in figure C-1. Within the wave number integration loop in “TRANS”, spectral values of transmission, incident sky radiance, and incident solar irradiance are stored in arrays Tau(V), Nsky(V), and Ho(V), respectively. Outside the wave number integration loop these values are recalled for the sea radiance calculation by subroutine “Sky” (or subroutine “Sun” if IEMSCT = 2).

The modified version of “DRIVER” is contained in Appendix B along with a detailed flowchart of its modifications. Appendix C contains the source code and a flowchart for the modified version of “TRANS”, and Appendix D contains new code for the sea radiance calculation.

11. CONCLUSION

SeaRad, a modification of MODTRAN2, computes sea radiance between 52.63 cm^{-1} and 25000 cm^{-1}. Preliminary comparisons with data show that *SeaRad* has an approximate accuracy of several °C in the infrared.

SeaRad is currently designed for a single pixel and takes approximately 10 s to execute. Each time a new geometry is chosen by the user, *SeaRad* recalculates the source radiance and the path radiance and transmission. However, only the path properties change significantly from one pixel to the next in a typical ocean image. If *SeaRad* were redesigned to apply to sea images, the speed per pixel could be reduced, up to a factor of almost four, by calculating values of source radiance just once for the entire image.

12. REFERENCES

Berk, A., L. S. Bernstein, and D. C. Robertson. 1989. "MODTRAN: A Moderate Resolution Model for LOWTRAN 7," Report GL–TR–89–0122. Air Force Geophysics Laboratory, Bedford, MA.

Cox, C. and W. Munk. 1954. "Measurement of the Roughness of the Sea Surface from Photographs of the Sun's Glitter," *Journal of the Optical Society of America* 44: 838–850.

Cox, C. and W. Munk. 1956. "Slopes of the Sea Surface Deduced from Photographs of Sun Glitter," *Scripps Institution of Oceanography Bulletin* 6: 401–487.

Fenn, R. W., S. A. Clough, W. O. Gallery, R. E. Good, F. X. Kneizys, J. D. Mill, L. S. Rothman, E. P. Shettle, and F. E. Volz. 1985. "Optical and Infrared Properties of the Atmosphere," In *Handbook of Geophysics and the Space Environment.* A. S. Jursa, Ed. Air Force Geophysics Laboratory, Bedford, MA.

Hale, G. M. and M. R. Querry. 1973. "Optical Constants of Water in the 200 nm to 200 μm Wavelength Region," *Applied Optics* 3: 555–563.

Isaacs, R. G., W. C. Wang, R. D. Worsham, and S. Goldenberg. 1986. "Multiple Scattering Treatment for Use in the LOWTRAN and FASCODE Models," Report AFGL–TR–86–0073: Air Force Geophysics Laboratory, Bedford, MA.

Kneizys, F. X., E. P. Shettle, L. W. Abreu, J. H. Chetwynd, G. P. Anderson, W. O. Gallery, J. E. A. Selby, and S. A. Clough. 1988. "Users Guide to LOWTRAN 7," Report AFGL–TR–88–0177. Air Force Geophysics Laboratory, Bedford, MA.

Kneizys, F. X., E. P. Shettle, W. O. Gallery, J. H. Chetwynd, L. W. Abreu, J. E. A. Selby, S. A. Clough, and R. W. Fenn. 1983. "Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 6," Report AFGL–TR–83–0187. Air Force Geophysics Laboratory, Bedford, MA.

Kneizys, F. X., E. P. Shettle, W. O. Gallery, J. H. Chetwynd, L. W. Abreu, J. E. A. Selby, R. W. Fenn, and R. A. McClatchey. 1980. "Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 5," Report AFGL–TR–80–0067. Air Force Geophysics Laboratory, Bedford, MA.

Kneizys, F. X., J. E. A. Selby, J. H. Chetwynd, and R. A. McClatchey. 1978. "Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 4," Report AFGL–TR–78–0053. Air Force Geophysics Laboratory, Bedford, MA.

Plass, G. N., G. W. Kattawar, and J. A. Guinn. 1975. "Radiative Transfer in the Earth's Atmosphere and Ocean: Influence of Ocean Waves," *Applied Optics* 14: 1924–1936.

Querry, M. R., W. E. Holland, R. C. Waring, L. M. Earls, and M. D. Querry. 1977. "Relative Reflectance and Complex Refractive Index in the Infrared for Saline Environmental Waters," *Journal of Geophysical Research* 82: 1425–1433.

Selby, J. E. A., E. P. Shettle, and R. A. McClatchey. 1976. "Atmospheric Transmittance from 0.25 to 28.5 μm: Supplement LOWTRAN 3B," Report AFGL–TR–76–0258. Air Force Geophysics Laboratory, Bedford, MA.

Selby, J. E. A. and R. A. McClatchey. 1975. "Atmospheric Transmittance from 0.25 to 28.5 μm: Computer Code LOWTRAN3," Report AFGL–TR–72–0255. Air Force Geophysics Laboratory, Bedford, MA.

Selby, J. E. A. and R. A. McClatchey. 1972. "Atmospheric Transmittance form 0.25 to 28.5 μm: Computer Code LOWTRAN 2," Report AFGL–TR–72–0745. Air Force Geophysics Laboratory, Bedford MA.

Stratton, J. A. 1941. *Electromagnetic Theory*, pp. 505 ff., McGraw–Hill, New York, NY.

Zeisse, C. R. 1994. "Radiance of the Ocean Horizon," NRaD TR 1660 (April). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Zeisse, C. R. 1995. "Radiance of Ocean Horizon," *Journal of the Optical Society*, vol. A, pp. 2022–2030.

APPENDIX A
SeaRad INPUT AND OUTPUT FILES

“TAPE5RAD.STD” INPUT FILE

C:\MOD2\TAPE5RAD.FIL 7/20/95

```
F   6    3    1    1    0    0    0    0    0    0    0    0    0 288.15    0.00
    3    0    0    5    0    0   10.000   10.000   10.000      .000     .000
    00.023      .000  100.000      .000      .000     0.00    0    90.000    T
       940       950       10         5
    0
```

"OUT" FILE

```
C:\MOD2\OUT.FIL 7/20/95

***** SEARAD, A MODIFICATION OF LOWTRAN7 *****

DATE: 07/20/95                                        TIME: 15:11:38

THERMAL RADIANCE MODE

MULTIPLE SCATTERING USED

MARINE AEROSOL MODEL USED

         WIND SPEED          =     10.00 M/SEC
         WIND SPEED          =     10.00 M/SEC, 24 HR AVERAGE
         RELATIVE HUMIDITY   =     50.00 PERCENT
         AIRMASS CHARACTER   =      5
         VISIBILITY          =     10.00 KM

SLANT PATH TO SPACE

          H1      =      0.023 KM
          HMIN    =      0.000 KM
          ANGLE   =    100.000 DEG

FREQUENCY RANGE

          IV1     =        940 CM-1  (  10.64 MICROMETERS)
          IV2     =        950 CM-1  (  10.53 MICROMETERS)
          IDV     =         10 CM-1
          IFWHM   =          5 CM-1
          IFILTER =          0

SUMMARY OF THE GEOMETRY CALCULATION

          H1      =      0.023 KM
          H2      =      0.000 KM
          ANGLE   =    100.000 DEG
          RANGE   =      0.133 KM
          BETA    =      0.001 DEG
          PHI     =     80.001 DEG
          HMIN    =      0.000 KM
          BENDING =      0.000 DEG
          LEN     =          0

SEA AT 288.15 K REPLACES BLACK BODY BOUNDARY

          UPWIND  =     90.000 DEG EAST OF LINE OF SIGHT

RECEIVED RADIANCE VALUES

          PATH TO FOOTPRINT          0.01814 W M-2 SR-1  (AV. TRANS. 0.9776)
          SEA EMISSION          =    0.70712 W M-2 SR-1
          SKY REFLECTION        =    0.06125 W M-2 SR-1
          SUN GLINT             =    0.00000 W M-2 SR-1

          TOTAL RADIANCE        =    0.78652 W M-2 SR-1
          BLACK BODY TEMP.      =       6.7 C
```

"TAPE5.SEA" FILE

C:\MOD2\TAPE5SEA.FIL 7/20/95

```
3
 0.000     0.000     57.296     0.000     0.000     0.000     0     90.000     T
3
 0.000     0.000     73.148     0.000     0.000     0.000     0     90.000     T
3
 0.000     0.000     89.000     0.000     0.000     0.000     0     90.000     T
```

APPENDIX B
MODIFIED SUBROUTINE "DRIVER"

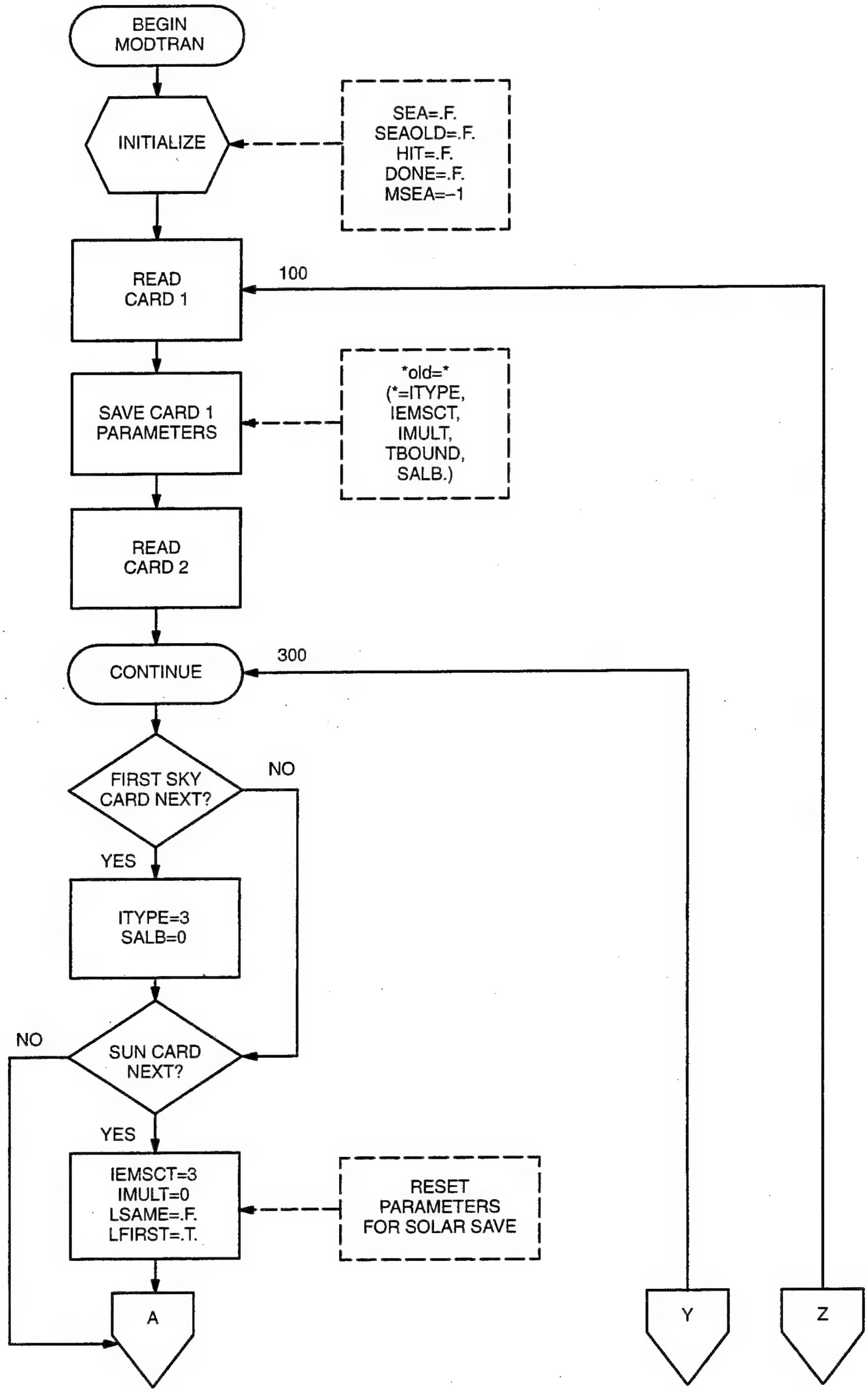


Figure B-1. Detailed flowchart for modified subroutine “DRIVER”.

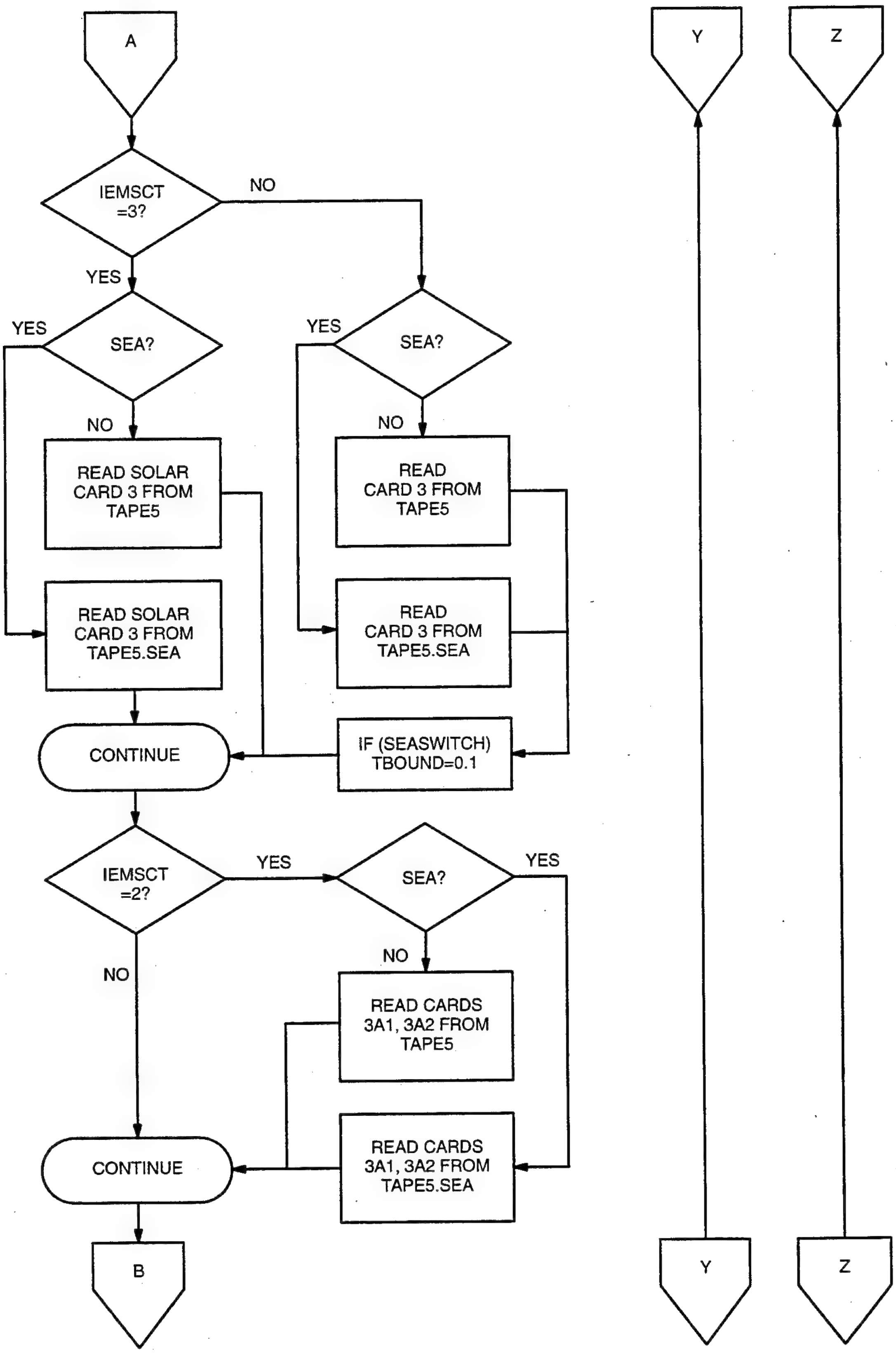


Figure B-1. Detailed flowchart for modified subroutine "DRIVER". (Continued)

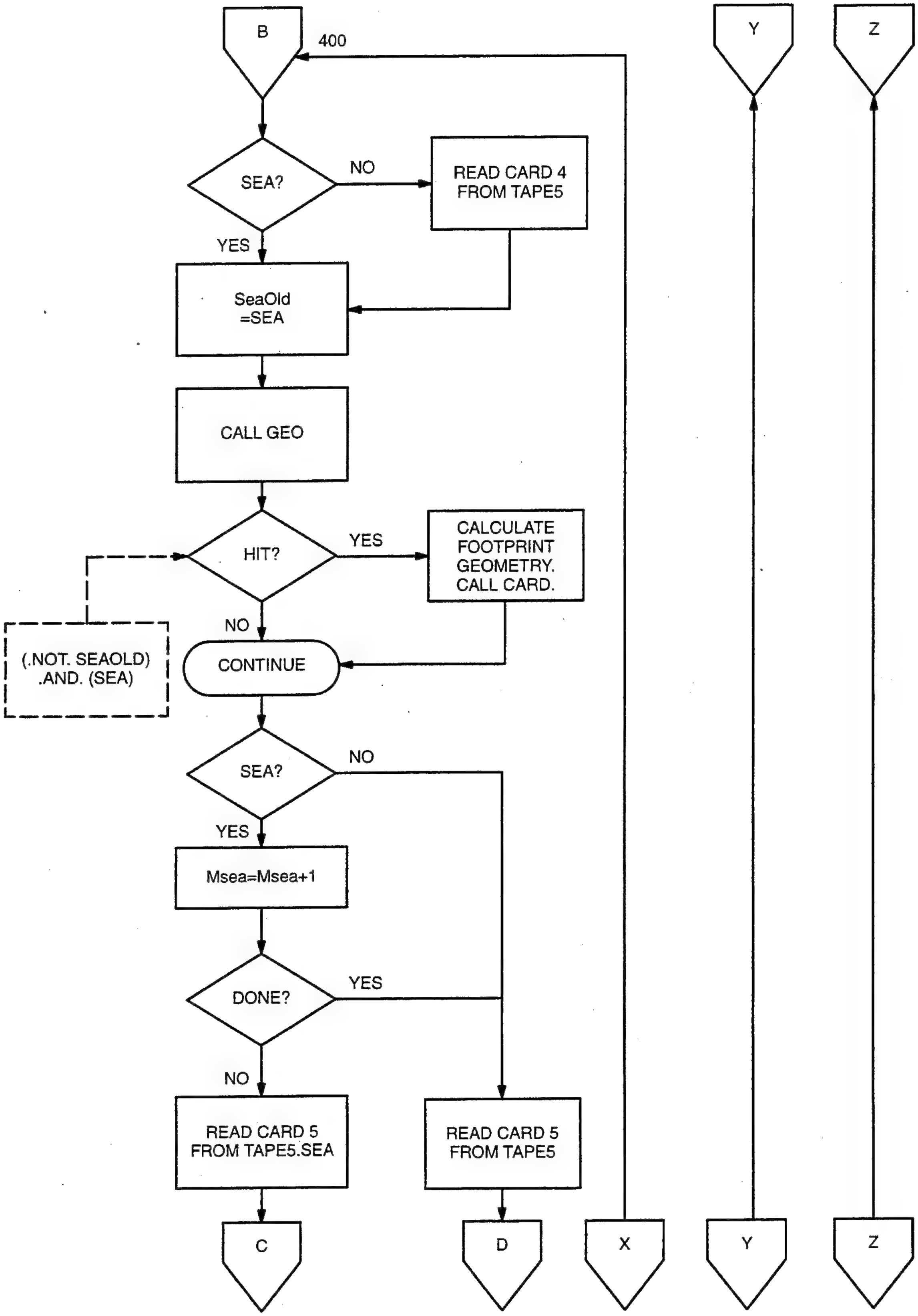


Figure B-1. Detailed flowchart for modified subroutine “DRIVER”. (Continued)

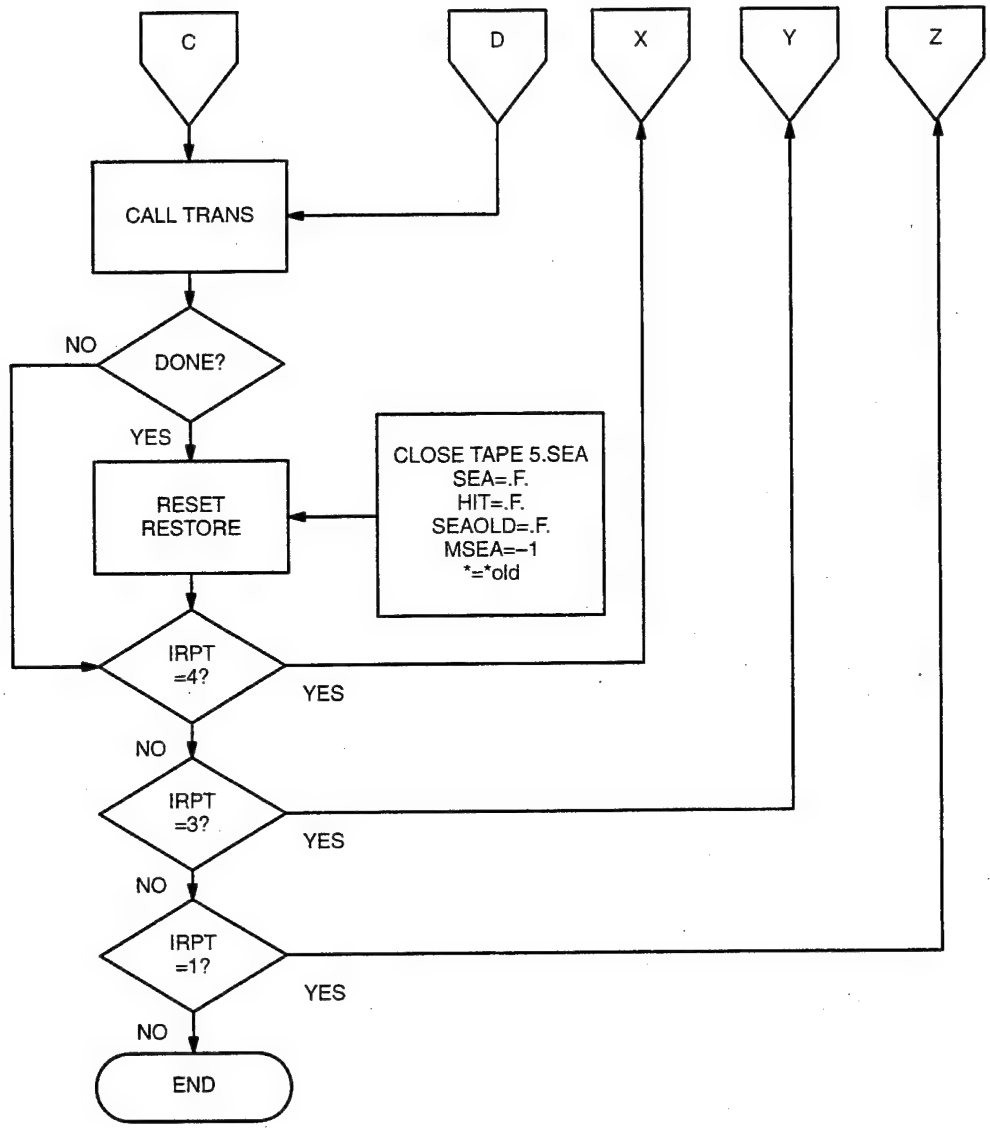


Figure B-1. Detailed flowchart for modified subroutine “DRIVER”. (Continued)

```
      SUBROUTINE DRIVER
      COMMON RELHUM(34),HSTOR(34),ICH(4),VH(17),TX(63),W(63)
C     COMMON             WPATH(68, 63),TBBY(68)
      COMMON IMSMX,WPATH(102,63),TBBY(102),PATM(102),NSPEC,KPOINT(12)
      COMMON ABSC(5,47),EXTC(5,47),ASYM(5,47),VX2(47),AWCCON(5)
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,ITR,
     +        Isky,Isun,Ipath
      COMMON /CARD1/ MODEL,ITYPE,IEMSCT,M1,M2,M3,IM,NOPRT,TBOUND,SALB
     1   ,MODTRN
      LOGICAL MODTRN
      logical ground
      logical lsame
      LOGICAL SeaSwitch,Sea,SeaOld,Hit,Done
      COMMON /CARD1A/ M4,M5,M6,MDEF,IRD1,IRD2
      COMMON /CARD2/ IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,
     1    RAINRT
      COMMON /CARD2A/ CTHIK,CALT,CEXT
      COMMON /CARD2D/ IREG(4),ALTB(4),IREGC(4)
      COMMON /CARD3/ H1,H2,ANGLE,RANGE,BETA,RE,LEN,Psi,SeaSwitch
      COMMON /Card3A1/ IPARM,IPH,IDAY,ISOURC
      COMMON /Card3A2/ PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
      COMMON /CARD4/ IV1,IV2,IDV,IFWHM,IFILTER
      COMMON /CNSTNS/ PIX,CA,DEG,GCAIR,BIGNUM,BIGEXP
      COMMON /CNTRL/ KMAX,M,IKMAX,NL,ML,IKLO,ISSGEO,IMULT
      COMMON /MODEL/ ZM(34),PM(34),TM(34),RFNDX(34),DENSTY(63,34),
     1  CLDAMT(34),RRAMT(34),EQLWC(34),HAZEC(34)
      COMMON /SOLS/ AH1(68),ARH(68),
     1  WPATHS(102,63),PA(68),PRX(68),ATHETA(35),ADBETA(35),LJ(69),
     2  JTURN,ANGSUN,CSZEN(68),TBBYS(102,12),PATMS(102,12)
      COMMON /MART/ RHH
      COMMON /USRDTA/ NANGLS,ANGF(50),F(4,50)
      COMMON /MDLZ/ HMDLZ(8)
      COMMON /ZVSALY/ ZVSA(10),RHVSA(10),AHVSA(10),IHVSA(10)
      CHARACTER*4 HHAZE,HSEASN,HVULCN,BLANK,HMET,HMODEL,HTRRAD
      COMMON /TITL/ HHAZE(5,16),HSEASN(5,2),HVULCN(5,8),BLANK,
     1  HMET(5,2),HMODEL(5,8),HTRRAD(6,4)
      COMMON /VSBD/ VSB(10)
C     COMMON /MNLT/TBBSS(68),TBBMS(34),WPMS(34,63),IMSMX,WPMSS(34,63)
      COMMON /PATH/PL(68),QTHETA(68),ITEST,HI,HF,AHT(68),tph(68)
      COMMON /AERTM/TAE7,TAE12,TAE13,TAE14,TAE16
      common /graund/gndalt
      common /small3/small
      common /solar/lsame
      PARAMETER (Kr = 216, Kv = 400)
      COMMON /Filters/ FLIST(5,6),
     +                 FILTER1(45), BB1(Kr), FILTER2(54), BB2(Kr),
     +                 FILTER3(39), BB3(Kr), FILTER4(47), BB4(Kr),
     +                 FILTER5(101),BB5(Kr), FILTER6(75), BB6(Kr)
      COMMON /Constants/ pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      COMMON /Geometry/ Tsun,Psun,Tr,Pr
      COMMON /Sea/ Sea,Hit,Msea,TBOUNDold,IEMSCTold
      COMMON /SeaIndex/ Alpha01(100), Alpha02(20),
     +                  Beta01 (100), Beta02 (20)
      logical lfirst
      data lfirst/.true./
      REAL infinity
      CHARACTER*8  Date$, Time$
```

```
      CHARACTER*14 Prog$
      INTEGER*4 Istart, Iend
C     First, get starting time to measure total execution time:
      CALL TIMER(Istart)
c                                                                       driv 550
c     lfirst is true when first solar parameters are read in a series   driv 560
c     of runs involving solar parameters.                               driv 570
c                                                                       driv 580
C*****HDATE AND HTIME CARRY THE DATA AND TIME AND MUST BE DOUBLE         driv 590
C*****PRECISION ON A 32 BIT WORD COMPUTER                                driv 600
C@    DOUBLE PRECISION HDATE,HTIME                                      driv 610
      DIMENSION PLST(68),CSENSV(68),QTHETS(68)                          driv 620
      DATA IRPT / 0 /                                                   driv 630
C*****IRD, IPR, AND IPU ARE UNIT NUMBERS FOR INPUT, OUTPUT, AND          driv 640
C*****IPR1 = OUTPUT OF MOLECULAR TRANSMITTANCE                           driv 650
      DATA        MAXGEO    /     68/                                   driv 660
      small =     2.0                                                   driv 520
      IP4 = 14
      IRD = 5                                                           driv 670
      IPR = 6                                                           driv 680
      IP6 = 16
      IP6S= 26
      IPU = 7                                                           driv 690
      IP7 = 17
      IPR1= 8                                                           driv 700
      IP8 = 18
      IRDS = 29
      ITR = 30
      ISCRCH = 10                                                       driv 710
      ITM    = 31
      Isky   = 32
      Isun   = 33
      Ipath = 34
      OPEN (IRD, FILE='TAPE5',     STATUS='OLD')                        driv 720
      OPEN (IPR, FILE='TAPE6',     STATUS='UNKNOWN')                    driv 730
      OPEN (IP6, FILE='OUT',       STATUS='UNKNOWN')
      OPEN (IPU, FILE='TAPE7',     STATUS='UNKNOWN')                    driv 740
      OPEN (IP7, FILE='TAPE7.PLT',STATUS='UNKNOWN')
      OPEN (IPR1,FILE='TAPE8',     STATUS='UNKNOWN')                    driv 750
      OPEN (IP8, FILE='TAPE8.PLT',STATUS='UNKNOWN')
      OPEN (IP4, FILE='OUT.PLT',   STATUS='UNKNOWN')
      OPEN (ITR, FILE='TRANS.PLT',STATUS='UNKNOWN')
      OPEN (ISCRCH,STATUS='SCRATCH',FORM='UNFORMATTED')                 driv 760
      OPEN (Isky, FILE='Sky.plt', STATUS='UNKNOWN')
      OPEN (Isun, FILE='Sun.plt', STATUS='UNKNOWN')
      OPEN (Ipath,FILE='Path.plt',STATUS='UNKNOWN')
      OPEN (ITM, FILE='TIME',     STATUS='UNKNOWN')

C                                                                       driv 770
C     ALTITUDE PARAMETERS                                               driv 780
C                                                                       driv 790
C     ZMDL  COMMON/MODEL/  THE ALTITUDES USED IN LOWTRAN                driv 800
C     ZCVSA,ZTVSA,ZIVSA   CARD 3.3 LOWTRAN FOR VSA INPUT                driv 810
C     ZVSA  NINE ALTITUDES GEN BY VSA ROUTINE                           driv 820
C                                                                       driv 830
      Pix=2.0*ASIN(1.0)                                                 driv 840
      CA=Pix/180.                                                       driv 850
```

```
      DEG= 1.0/CA                                                       driv 860
      pi        = Pix
      r2d       = 180./pi
      d2r       = pi/180.
      epsilon   = d2r*0.2659
      delta     = 1.4E-6
      onem      = 1. - delta
      onep      = 1. + delta
      infinity = 999999
      RANGE=0.0                                                         driv 870
C*****GCAIR IS THE GAS CONSTANT FOR AIR IN UNITS OF MB/(GM CM-3 K)      driv 880
      GCAIR = 2.87053E+3                                                driv 890
C*****BIGNUM AND BIGEXP ARE THE LARGEST NUMBER AND THE LARGEST ARGUMENT driv 900
C*****EXP ALLOWED AND ARE MACHINE DEPENDENT. THE NUMBERS USED HERE ARE Fdriv 910
C*****A TYPICAL 32 BIT-WORD COMPUTER.                                   driv 920
      BIGNUM = 1.0E35                                                   driv 930
      BIGEXP = 87.0                                                     driv 940
C     THE VALUES FOR BIGNUM AND BIGEXP FOLLOW THE                       driv 950
C     DESCRIPTION UNDER EXP FUNCTION IN "IBM SYSTEM 360/                driv 960
C     AND SYSTEM 370 FORTRAN IV LANGUAGE"                               driv 970
C     BIGNUM = 4.3E68                                                   driv 980
C     BIGEXP = 174.6                                                    driv 990
      KMAX=63                                                           driv1000
C*****NL IS THE NUMBER OF BOUNDARIES IN THE STANDARD MODELS 1 TO 6      driv1010
C*****BOUNDARY 34 (AT 99999 KM) IS NO LONGER USED                       driv1020
      NL = 33                                                           driv1030
**********************************************************************
      Sea    = .FALSE.
      SeaOld = .FALSE.
      Hit    = .FALSE.
      Msea   = -1
      Done   = .FALSE.
**********************************************************************
C*****CALL TIME AND DATE:                                               driv1040
C*****THE USER MAY WISH TO INCLUDE SUBROUTINES FDATE AND FCLOCK WHICH   driv1050
C*****RETURN THE DATE AND TIME IN MM/DD/YY AND HH.MM.SS FORMATS         driv1060
C*****RESPECTIVELY. THE REQUIRED ROUTINES FOR A CDC 6600 ARE INCLUDED ATdriv1070
C*****THE MAIN PROGRAM IN COMMENT CARDS.                                driv1080
C@    CALL FDATE(HDATE)                                                 driv1090
C@    CALL FCLOCK(HTIME)                                                driv1100
      CALL DATE (Date$)
      CALL TIME (Time$)
C                                                                       driv1110
C*****START CALCULATION                                                 driv1120
C                                                                       driv1130
C                                                                       driv1140
100   DO 10 II = 1,4                                                    driv1150
10    IREG(II) = 0                                                      driv1160
      WRITE(IPR,1000)                                                   driv1170
1000  FORMAT('1',20X,'*****  MODTRAN   *****')                          driv1180
C@    WRITE(IPR,1010) HDATE,HTIME                                       driv1190
1010  FORMAT('1',20X,'*****  MODTRAN   *****',10X,2(1X,A8,1X))          driv1200
      DO 80 I=1,4                                                       driv1210
          DO 80 J=1,40                                                  driv1220
              ABSC(I,J)=0.                                              driv1230
              EXTC(I,J)=0.                                              driv1240
 80   ASYM(I,J)=0.                                                      driv1250
```

```
      JPRT = 0                                                          driv1260
      IKLO=1                                                            driv1270
C                                                                       driv1280
C*****CARD 1                                                            driv1290
C                                                                       driv1300
      READ(IRD,'(L1,I4,12I5,F8.3,F7.2)')MODTRN,MODEL,ITYPE,
     +          IEMSCT,IMULT,M1,M2,M3,M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB driv1340
 1110 FORMAT(13I5,F8.3,F7.2)                                            driv1350
***********************************  Save parameters to restore them
      ITYPEold   = ITYPE
      IEMSCTold = IEMSCT
      IMULTold   = IMULT
      If (TBOUND .EQ. 0.) TBOUND = 0.1
      TBOUNDold = TBOUND
      SALBold    = SALB
*********************************** in case new geometry cards are
c                                    later introduced via file TAPE5.SEA
      IF (MODTRN) THEN
              Prog$ = 'MODTRAN2 *****'
          ELSE
              Prog$ = 'LOWTRAN7 *****'
      END IF
      WRITE (IP6,  1018) Prog$
1018  FORMAT(15X, '***** SEARAD, A MODIFICATION OF ', A14)
      WRITE (IP6,  1020) Date$, Time$
1020  FORMAT (/, 'DATE:', 1X, A8, T60, 'TIME:', 1X, A8)
      SELECT CASE (IEMSCT)
          CASE (0)
              WRITE (IP6, '(/, 18HTRANSMITTANCE MODE)')
          CASE (1)
              WRITE (IP6, '(/, 21HTHERMAL RADIANCE MODE)')
          CASE (2)
              WRITE (IP6, '(/, 32HTHERMAL PLUS SOLAR RADIANCE MODE)')
          CASE (3)
              WRITE (IP6, '(/, 21HSOLAR IRRADIANCE MODE)')
      END SELECT
c
      SELECT CASE (IMULT)
          CASE (0)
              PRINT *, "IMULT = ", IMULT, ":  BEWARE OF BEN-SHALOM"
              WRITE (IP6, '(/, 22HSINGLE SCATTERING USED)')
          CASE (1)
              WRITE (IP6, '(/, 24HMULTIPLE SCATTERING USED)')
      END SELECT
c
      WRITE(IPR,'(15H0 CARD 1   *****,L1,I4,12I5,F8.3,F7.2)')MODTRN,MODELdriv1380
     1  ,ITYPE,IEMSCT,IMULT,M1,M2,M3,M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB driv1390
 1111 FORMAT('0 CARD 1   *****',13I5,F8.3,F7.2)                         driv1400
C     IF(IMULT .EQ. 1 .AND. NOPRT.EQ. 1) NOPRT = 0                      driv1410
C                                                                       driv1420
C     SET THE NUMBER OF SPECIES TREATED WITH THE 1 CM-1 BAND MODEL.     driv1430
C     ALSO, FOR EACH SPECIES, SET THE POINTER WHICH MAPS THE HITRAN     driv1440
C     NUMERICAL LABEL TO THE LOWTRAN NUMERICAL LABEL.                   driv1450
C                                                                       driv1460
      NSPEC=12                                                          driv1470
      KPOINT( 1)=17                                                     driv1480
      KPOINT( 2)=36                                                     driv1490
```

```
      KPOINT( 3)=31
      KPOINT( 4)=47
      KPOINT( 5)=44
      KPOINT( 6)=46
      KPOINT( 7)=50
      KPOINT( 8)=54
      KPOINT( 9)=56
      KPOINT(10)=55
      KPOINT(11)=52
      KPOINT(12)=11
C
      IRD1 = 0
      IRD2 = 0
      IF (MODEL.EQ.0) LEN = 0
      IF((MODEL.EQ.0) .OR. (MODEL.EQ.7)) GO TO 110
      IF(M1.EQ.0) M1=MODEL
      IF(M2.EQ.0) M2=MODEL
      IF(M3.EQ.0) M3=MODEL
      IF(M4.EQ.0) M4=MODEL
      IF(M5.EQ.0) M5=MODEL
      IF(M6.EQ.0) M6=MODEL
      IF(MDEF.EQ.0) MDEF=1
110   CONTINUE
      M=MODEL
      NPR = NOPRT
C*****CARD 2 AEROSOL MODEL
      READ(IRD,1200)IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,
     1  RAINRT,GNDALT
1200  FORMAT(6I5,5F10.3)
      WRITE(IPR,1201)IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,
     1  RAINRT,GNDALT
      IF(GNDALT.GT.0.) WRITE(IPR,1199)GNDALT
1199  FORMAT(1H0,'  GNDALT =',F10.2)
      IF(GNDALT.GE.6.0) THEN
          WRITE(IPR,1202)GNDALT
          GNDALT=0.
      ENDIF
1201  FORMAT('0 CARD 2  *****',6I5,5F10.3)
1202  FORMAT('0 GNDALT GT 6.0 RESET TO ZERO, GNDALT WAS',F10.3)
C
      IF(VIS.LE.0.0.AND.IHAZE.GT.0) VIS=VSB(IHAZE)
      RHH= 0.
      IF(MODEL.EQ.0.OR.MODEL.EQ.7) GO TO 205
      IF((MODEL.EQ.3.OR.MODEL.EQ.5).AND.ISEASN.EQ.0) ISEASN=2
C
      IF(IVSA.EQ.1 .AND. IHAZE.EQ.3)
     1  CALL MARINE(VIS,MODEL,WSS,WHH,ICSTL,EXTC,ABSC,1)
      ICH(1)=IHAZE
      ICH(2)=6
      ICH(3)=9+IVULCN
205   IF(RAINRT.EQ.0) GO TO 210
      WRITE(IPR,1205) RAINRT
1205  FORMAT('0 RAIN MODEL CALLED, RAIN RATE = ',F9.2,' MM/HR')
 210  ICH(4)=18
      IF(ICH(1).LE.0)ICH(1)=1
      IF(ICH(3).LE.9)ICH(3)=10
      IF(ICLD.GE.1 .AND. ICLD.LE.11) THEN
```

```
            ICH(4)=ICH(3)
            ICH(3)=ICH(2)
            ICH(2)=ICLD
      END IF
      IFLGA=0
      IFLGT=0
      CTHIK=-99.
      CALT=-99.
      CEXT=-99.
      ISEED=-99
      IF(ICLD .LT. 18) GO TO 230
C*****CARD 2A CIRRUS CLOUDS
      READ(IRD,1210)CTHIK,CALT,CEXT,ISEED
1210  FORMAT(3F10.3,I10)
      WRITE(IPR,1211)CTHIK,CALT,CEXT,ISEED
1211  FORMAT('0 CARD 2A *****',3F10.3,I10)
230   CONTINUE
C*****CARD 2B VERTICAL STRUCTURE ALGORITHM
      ZCVSA=-99.
      ZTVSA=-99.
      ZINVSA=-99.
C
      IF( IVSA. EQ. 0 ) GO TO 240
      READ (IRD,1230)  ZCVSA,ZTVSA,ZINVSA
1230  FORMAT(3F10.3)
      WRITE(IPR,1231)ZCVSA,ZTVSA,ZINVSA
1231  FORMAT('0 CARD 2B *****',3F10.3)
C
      CALL VSA(IHAZE,VIS,ZCVSA,ZTVSA,ZINVSA,ZVSA,RHVSA,AHVSA,IHVSA)
C
C     END OF VSA MODEL SET-UP
C
240   IF (MODEL.NE.0 .AND. MODEL.NE.7 ) ML=NL
      MDELS=MODEL
      DO 250 I=1,5
          IF(MDELS.NE.0)HMODEL(I,7)=HMODEL(I,MDELS)
250   IF(MDELS.EQ.0)HMODEL(I,7)=HMODEL(I,8)
C
      IF(IM .EQ. 1) THEN
          IF((MODEL.EQ.7.AND.IM.EQ.1) .OR.(MODEL.EQ.0)) THEN
C
C*****CARD 2C  USER SUPPLIED ATMOSPHERIC PROFILE
C
              READ (IRD,1250) ML,IRD1,IRD2,(HMODEL(I,7),I=1,5)
1250          FORMAT(3I5,18A4)
              WRITE(IPR,1251)ML,IRD1,IRD2,(HMODEL(I,7),I=1,5)
              IF(IVSA.EQ.1)CALL RDNSM
1251          FORMAT('0 CARD 2C *****',3I5,18A4)
          ENDIF
      ENDIF
      M=7
      CALL AERNSM(JPRT,  GNDALT)
      IF(ICLD .LT. 20) GO TO 260
C
C     SET UP CIRRUS MODEL
C
      IF(CTHIK.NE.0) IFLGT=1
```

```
      IF(CALT.NE.0)   IFLGA=1
      IF(ISEED.EQ.0) IFLGT=2
      IF(ISEED.EQ.0) IFLGA=2
      CALL CIRRUS(CTHIK,CALT,ISEED,CPROB,CEXT)
      WRITE(IPR,1220)
1220  FORMAT(15X,'CIRRUS ATTENUATION INCLUDED (N O A A CIRRUS) ')
      IF(IFLGT.EQ.0) WRITE(IPR,1221) CTHIK
1221  FORMAT(15X,'CIRRUS ATTENUTION STATISTICALLY DETERMENED TO BE',
     1  F10.3,'KM')
      IF(IFLGT.EQ.1) WRITE(IPR,1222) CTHIK
1222  FORMAT(15X,'CIRRUS THICKNESS USER DETERMINED TO BE',F10.3,'KM')
      IF(IFLGT.EQ.2) WRITE(IPR,1223) CTHIK
1223  FORMAT(15X,'CIRRUS THICKNESS DEFAULTED TO MEAN VALUE OF    ',
     1  F10.3,'KM')
      IF(IFLGA.EQ.0) WRITE(IPR,1224)CALT
1224  FORMAT(15X,'CIRRUS BASE ALTITUDE STATISCALLY DETERMINED TO BE',
     1  F10.3,' KM')
      IF(IFLGA.EQ.1) WRITE(IPR,1225) CALT
1225  FORMAT(15X,'CIRRUS BASE ALTITUDE USER DETERMINED TO BE',
     1  F10.3,' KM')
      IF(IFLGA.EQ.2) WRITE(IPR,1226) CALT
1226  FORMAT(15X,'CIRRUS BASE ALTITUDE DEFAULTED TO MEAN VALUE OF',
     1  F10.3,'KM')
      WRITE(IPR,1227)CPROB
1227  FORMAT(15X,'PROBABILTY OF CLOUD OCCURRING IS',F7.1,' PERCENT')
C
C       END OF CIRRUS MODEL SET UP
C
260   CONTINUE
C
C
C*****CARD 2E
C
      IF((IHAZE.EQ.7).OR.(ICLD.EQ.11)) THEN
C
C*****     CARD 2E USER SUPPLIED AEROSOL EXTINCTION, ABSORPTION, AND
C          ASYMMETRY
           CALL RDEXA
C
      ENDIF
300   CONTINUE

      IPARM =-99
      IPH   =-99
      IDAY  =-99
      ISOURC=-99
C
      PARM1 =-99.
      PARM2 =-99.
      PARM3 =-99.
      PARM4 =-99.
      GMT   =-99.
      PSIPO =  0.
      ANGLEM=-99.
      G     =-99.
C
C*****CARD 3 GEOMETERY PARAMETERS
```

```
C
      IF ((SEA) .AND. (Msea .EQ. 0)) THEN
C         the first sky card is next.
C         Set emissivity to zero (TBOUND is already zero) and ITYPE to 3
C         for calculations coming up with cards in TAPE5.SEA:
          ITYPE  = 3
          SALB   = 0.0
      END IF
*** Set mode to sun irradiance (if a sun card will be next) *********
      IF ((Sea) .AND. (IEMSCTold .EQ. 2) .AND. (Msea .EQ. 3)) THEN
          IEMSCT = 3
          IMULT  = 0
          LFIRST = .TRUE.
          LSAME  = .FALSE.
      END IF
      IF (IEMSCT .EQ. 3) GO TO 315
***** Read introduced geometry cards from file TAPE5.SEA ***************
      IF (SEA) THEN
              READ(IRDS,1312)H1,H2,ANGLE,RANGE,BETA,RO,LEN,Psi,SeaSwitch
           ELSE
              READ (IRD,1312)H1,H2,ANGLE,RANGE,BETA,RO,LEN,Psi,SeaSwitch
      END IF
***** and remove the boundary (in sea AND sky) for a sea calculation ***
      IF (SeaSwitch) TBOUND = 0.1
1312  FORMAT(6F10.3,I5,F10.3,L5)
      WRITE(IPR,1313)H1,H2,ANGLE,RANGE,BETA,RO,LEN,Psi,SeaSwitch
1313  FORMAT('0 CARD 3   *****',6F10.3,I5,F10.3,L5)
      GO TO 320
C
C*****CARD 3 FOR DIRECTLY TRANSMITTED SOLAR RADIANCE (IEMSCT = 3)
C
  315 CONTINUE
********* Read introduced sun card from file TAPE5.SEA **************
      IF (Sea) THEN
                  READ(IRDS,1316) H1,H2,ANGLE,IDAY,RO,ISOURC,ANGLEM
            ELSE
                  READ(IRD, 1316) H1,H2,ANGLE,IDAY,RO,ISOURC,ANGLEM
      END IF
*******************************************************************
 1316 FORMAT(3F10.3,I5,5X,F10.3,I5,F10.3)
      WRITE(IPR,1317) H1,H2,ANGLE,IDAY,RO,ISOURC,ANGLEM
 1317 FORMAT('0 CARD 3   *****',3F10.3,I5,5X,F10.3,I5,F10.3)
      ITYPE = 3
      RANGE = 0.0
      BETA = 0.0
      LEN = 0
C*****RO IS THE RADIUS OF THE EARTH
320   RE=6371.23
C      *********  ERRATA JULY 25
           IF(H1. LT. ZM(1)   ) THEN
           WRITE(IPR,905) H1,ZM(1)
905        FORMAT('  H1 LESS THAN FIRST ALT RESET  ',/
     X     ' H1 WAS ',F10.2,' 1ST ALT = ',F10.2)
            H1 = ZM(1)
      ENDIF
C        *********  END  ERRATA
      H1S    = H1
```

```
      H2S    = H2
      ANGLES = ANGLE
      RANGS  = RANGE
      BETAS  = BETA
      ITYPES =ITYPE
      LENS   = LEN
      IF (MODEL.EQ.0) RO = RE
      IF (MODEL.EQ.1) RE=6378.39
      IF (MODEL.EQ.4) RE=6356.91
      IF (MODEL.EQ.5) RE=6356.91
      IF (RO.GT.0.0) RE=RO
C
      IF (IEMSCT.NE.2) GO TO 330
C
C*****CARD 3A1
C
      IF (SEA) THEN
                  READ(IRDS,1320) IPARM,IPH,IDAY,ISOURC
            ELSE
                  READ(IRD,1320)  IPARM,IPH,IDAY,ISOURC
      END IF
1320  FORMAT(4I5)
      WRITE(IPR,1321) IPARM,IPH,IDAY,ISOURC
1321  FORMAT('0 CARD 3A1*****',4I5)
C
C*****CARD 3A2
C
      IF (SEA) THEN
                  READ(IRDS,1322) PARM1, PARM2, PARM3, PARM4,
     +                            GMT,PSIPO,ANGLEM,G
            ELSE
                  READ(IRD,1322)  PARM1, PARM2, PARM3, PARM4,
     +                            GMT,PSIPO,ANGLEM,G
      END IF
1322  FORMAT(8F10.3)
      WRITE(IPR,1323)PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
1323  FORMAT('0 CARD 3A2*****',8F10.3)
C
CSSISSISSISSISSI  CHANGES  BEGIN.
C
      REWIND(ISCRCH)
C
      IF (LFIRST .AND. IMULT .EQ. 1) THEN
C
C         SAVE SOLAR PARAMETERS FOR COMPARING LATER.
C         NOTE THAT LFIRST IS TRUE AND IMULT (MULTIPLE SOLAR SCATTERING)
         LFIRST = .FALSE.
         CALL SVSOLA(IPARM,IPH,IDAY,ISOURC,PARM1,PARM2,PARM3,PARM4,
     $        GMT,PSIPO,ANGLEM,
     $        ISAVE1,ISAVE2,ISAVE3,ISAVE4,SAVE1,SAVE2,SAVE3,SAVE4,
     $        SAVE5,SAVE6,SAVE7)
         LSAME = .FALSE.
C
      ELSEIF (IMULT .EQ. 1 .AND. IRPT .EQ. 3) THEN
C
C         NOW COMPARE SOLAR PARAMETERS; LSAME IS TRUE IF THEY MATCH.
         CALL COMPAR(IPARM,IPH,IDAY,ISOURC,PARM1,PARM2,PARM3,PARM4,
```

```
     $         GMT,PSIPO,ANGLEM,
     $         ISAVE1,ISAVE2,ISAVE3,ISAVE4,SAVE1,SAVE2,SAVE3,SAVE4,
     $         SAVE5,SAVE6,SAVE7,LSAME)
          CALL SVSOLA(IPARM,IPH,IDAY,ISOURC,PARM1,PARM2,PARM3,PARM4,
     $         GMT,PSIPO,ANGLEM,
     $         ISAVE1,ISAVE2,ISAVE3,ISAVE4,SAVE1,SAVE2,SAVE3,SAVE4,
     $         SAVE5,SAVE6,SAVE7)
      ELSE
C
C        GET READY FOR ANOTHER POSSIBLE FORTHCOMING SERIES OF MULTIPLE
C        SOLAR SCATTERING RUNS.
         LFIRST = .TRUE.
         LSAME = .FALSE.
      ENDIF
C
CSSISSISSISSISSI  CHANGES  END
C
      IF(IPH. EQ . 0) THEN
            IF(G. GE.  1.0) G =  .9999
            IF(G. LE. -1.0) G = -.9999
      ENDIF
      IF (IPH.NE.1) GO TO 330
C
C*****CARD 3B1 USER DEFINED PHASE FUNCTION
C
C*****READ USER DEFINED PHASE FUNCTION
C
      READ(IRD,1326)NANGLS
1326  FORMAT(I5)
      WRITE(IPR,1327)NANGLS
1327  FORMAT(' CARD 3B1*****',I5)
C
C*****CARD 3B2
C
      READ(IRD,1328)(ANGF(I),F(1,I),F(2,I),F(3,I),F(4,I),I=1,NANGLS)
1328  FORMAT(5E10.3)
      WRITE(IPR,1329)(ANGF(I),F(1,I),F(2,I),F(3,I),F(4,I),I=1,NANGLS)
1329  FORMAT('0 CARD 3B2*****',5E10.3)
C
  330 CONTINUE
C
      IF (IRPT .EQ. 3) THEN
          IF(IPARM .EQ. 1) CALL SUBSOL (PARM3,PARM4,GMT,IDAY)
          GO TO 555
      END IF
C
C*****CARD 4 WAVENUMBER
C
  400 CONTINUE
      IF (.NOT. SEA) THEN
          READ(IRD,'(5I10)')IV1,IV2,IDV,IFWHM,IFILTER
      END IF
  401 WRITE(IPR,'(15H0 CARD 4  *****,5I10)')IV1,IV2,IDV,IFWHM,IFILTER
      IF(IDV . LE. 0)THEN
         PRINT *,' ERROR IN IDV ',IDV
         IDV = 1
      ENDIF
```

```
      IF(IFWHM . LE. 0)THEN
         PRINT *,' ERROR IN IFWHM ',IFWHM
         IFWHM = 2
      ENDIF
      IF ((IFILTER .GE. 1) .AND. (IFILTER .LE. 6)) THEN
C              reset wavenumbers to span filter passband:
               W1  = FLIST(1, IFILTER)
               W2  = FLIST(2, IFILTER)
               IV1 = INT(1E4/W2) - IDV
               IV2 = INT(1E4/W1) + IDV
         ELSE
C              filter data are absent.  Reset to no filter at all:
               IFILTER = 0
      END IF
      IF (SeaSwitch) THEN
C        Check number of wavenumber steps. Reset, if necessary, to
C        prevent sea arrays from overflowing in "TRANS".
         Nv = (IV2 - IV1)/IDV
         IF (Nv .GE. Kv) IDV = (IV2 - IV1)/Kv + 1
      END IF
      WRITE(IP4, '(1H\, T20, 22HOUTPUT FILE FOR FILTER, I2,
     +              2H: , I5, 3H TO, I5, 9H CM-1 IN , I2,
     +              12H CM-1 STEPS., /1H\)') IFILTER, IV1, IV2, IDV
      WRITE(IP4, '(1H\, T65, 18H FILTERED RADIANCE)')
      WRITE(IP4, '(45H\                    ELEV.    ANGLE  RANGE    TRANS ,
     +         T49, 34H PATH      SEA        SKY        SUN,
     +         T88, 15H  TOTAL    TEMP.)')
      WRITE(IP4, '(45H\                   (mrad)     (deg)    (km)      (--) ,
     +         T68,13H (W m-2 sr-1), T100, 3H(C), /)')
      IF(IHAZE.EQ.3) THEN
C        IF(V1.LT.250.0 .OR. V2.LT.250.0) THEN
         IF(IV1.LT.250)THEN
               IHAZE=4
               WRITE (IPR,1203)
         ENDIF
 1203    FORMAT('0**WARNING** NAVY MODEL IS NOT USABLE BELOW 250CM-1',
     1   /,10X,' PROGRAM WILL SWITCH TO IHAZE=4 LOWTRAN 5 MARITIME',//)
      END IF
      IF (IRPT.EQ.4)  GO TO 550
cc    IF (IRPT.EQ.-4) GO TO 560
  500 CONTINUE
      IF (IRPT.EQ.3) GO TO 555
      WRITE(IPR,1410) (HTRRAD(I1,IEMSCT+1),I1=1,6)
 1410 FORMAT('0 PROGRAM WILL COMPUTE ',6A4)
      IF(ISOURC .EQ. 1) WRITE(IPR,1204)
 1204 FORMAT('   LUNAR SOURCE ONLY  ')
      IF (IMULT .EQ. 1) THEN
         IF(IEMSCT.EQ.0 .OR. IEMSCT.EQ.3 ) THEN
               WRITE(IPR,1411)
 1411          FORMAT('0 MULTIPLE SCATTERING HAS BEEN TURNED OFF ')
               WRITE (IP6,
     +           '(/, 39HMULTIPLE SCATTERING HAS BEEN TURNED OFF)')
               IMULT=0
         ELSE
               WRITE(IPR,1412)
         END IF
      END IF
```

```
1412  FORMAT('0 CALCULATIONS WILL BE DONE USING MULTIPLE SCATTERING ')  driv4870
      MDEL=MODEL                                                         driv4880
      IF(MDEL.EQ.0)MDEL=8                                                driv4890
      MM1=MDEL                                                           driv4900
      MM2=MDEL                                                           driv4910
      MM3=MDEL                                                           driv4920
      IF(M1.NE.0)MM1=M1                                                  driv4930
      IF(M2.NE.0)MM2=M2                                                  driv4940
      IF(M3.NE.0)MM3=M3                                                  driv4950
      IF(MODEL.EQ.0) GO TO 510                                           driv4960
      WRITE(IPR,1500) MM1,(HMODEL(I1,MM1),I1=1,5),MM2,(HMODEL(I2,MM2),   driv4970
     1  I2=1,5),MM3,(HMODEL(I3,MM3),I3=1,5)                              driv4980
1500  FORMAT('0 ATMOSPHERIC MODEL',/,                                    driv4990
     1  10X,'TEMPERATURE = ',I4,5X,5A4,/,                                driv5000
     1  10X,'WATER VAPOR = ',I4,5X,5A4,/,                                driv5010
     1  10X,'OZONE       = ',I4,5X,5A4)                                  driv5020
      WRITE(IPR,1501) M4,M5,M6,MDEF                                      driv5030
1501  FORMAT(20X,'  M4 = ',I5,' M5 = ',I5,' M6 = ',I5,' MDEF = ' ,I5)    driv5040
C                                                                        driv5050
510   IF(JPRT.EQ.0) GO TO 520                                            driv5060
      IF(ISEASN.EQ.0)ISEASN=1                                            driv5070
      IF(IVULCN.LE.0) IVULCN=1                                           driv5080
      IHVUL=IVULCN+10                                                    driv5090
      IF( IVULCN .EQ. 6) IHVUL = 11                                      driv5100
      IF( IVULCN .EQ. 7) IHVUL = 11                                      driv5110
      IF( IVULCN .EQ. 8) IHVUL = 13                                      driv5120
      IHMET=1                                                            driv5130
      IF(IVULCN.GT.1)IHMET=2                                             driv5140
      IF(IHAZE.EQ.0) GO TO 520                                           driv5150
      WRITE(IPR,1510)(HHAZE(I,IHAZE),I=1,5),VIS,(HHAZE(I2,6),I2=1,5),    driv5160
     1  (HHAZE(II,6),II=1,5),(HSEASN(IA,ISEASN),IA=1,5),                 driv5170
     2  (HHAZE(I3,IHVUL),I3=1,5),                                        driv5180
     3  (HVULCN(IB,IVULCN),IB=1,5),(HSEASN(IC,ISEASN),IC=1,5),           driv5190
     4  (HHAZE(I4,16),I4=1,5),(HMET(I5,IHMET),I5=1,5)                    driv5200
1510  FORMAT('0 AEROSOL MODEL',/,10X,'REGIME',                           driv5210
     A  T35,'AEROSOL TYPE',T60,'PROFILE',T85,'SEASON',/,/,               driv5220
     B  10X,'BOUNDARY LAYER (0-2 KM)',T35,5A4,T60,F5.1,                  driv5230
     C  ' KM VIS AT SEA LEVEL',/,10X,'TROPOSPHERE  (2-10KM)',T35,        driv5240
     D  5A4,T60,5A4,T85,5A4,/,10X,'STRATOSPHERE (10-30KM)',              driv5250
     E  T35,5A4,T60,5A4,T85,5A4,/,10X,'UPPER ATMOS (30-100KM)',          driv5260
     F  T35,5A4,T60,5A4)                                                 driv5270
520   CONTINUE                                                           driv5280
      IF(ITYPE.EQ.1) THEN
          WRITE(IPR,1515) H1,RANGE                                       driv5290
          WRITE(IP6,1515) H1,RANGE
      END IF
1515  FORMAT(/,'  HORIZONTAL PATH',//,
     1  8X,'ALTITUDE = ',F10.3,' KM',/,
     2  8X,'RANGE    = ',F10.3,' KM',/)                                  driv5310
      IF(ITYPE.EQ.2) THEN
          WRITE(IPR,1516) H1,H2,ANGLE,RANGE,BETA,LEN                     driv5320
          WRITE(IP6,1516) H1,H2,ANGLE,RANGE,BETA,LEN
      END IF
1516  FORMAT(/,'  SLANT PATH, H1 TO H2',//,
     1  10X,'H1     = ',F10.3,' KM',/,10X, 'H2     = ',F10.3,' KM',/,    driv5340
     2  10X,'ANGLE  = ',F10.3,' DEG',/,10X,'RANGE  = ',F10.3,' KM',/,    driv5350
     3  10X,'BETA   = ',F10.3,' DEG',/,10X,'LEN    = ',I6,/)             driv5360
```

```
      IF(ITYPE.EQ.3) THEN
          WRITE(IPR,1517) H1,H2,ANGLE                                   driv5370
          WRITE(IP6,1517) H1,H2,ANGLE
      END IF
1517  FORMAT(/,'SLANT PATH TO SPACE',//,
     1  10X, 'H1      = ',F10.3,' KM',/,
     2  10X, 'HMIN    = ',F10.3,' KM',/,                                driv5390
     3  10X, 'ANGLE   = ',F10.3,' DEG',/)                               driv5400
      IF (IEMSCT.NE.2) GO TO 550                                        driv5410
C                                                                       driv5420
C*****INTREPRET SOLAR SCATTERING PARAMETERS                             driv5430
C                                                                       driv5440
C                                                                       driv5450
      IF (IPARM.EQ.1) CALL SUBSOL (PARM3,PARM4,GMT,IDAY)                driv5460
C                                                                       driv5470
      WRITE (IPR,1530)                                                  driv5480
1530  FORMAT('0 SINGLE SCATTERING CONTROL PARAMETERS SUMMARY '/)        driv5490
      IF(IPARM.NE.2) WRITE (IPR,1532) PARM1,PARM2,PARM3,PARM4,GMT,PSIPO
     1,IDAY                                                             driv5510
1532  FORMAT(10X,'OBSERVER LATITUDE =',T35,F10.2,' DEG NORTH OF EQUATOR'driv5520
     1  ,/,10X,'OBSERVER LONGITUDE=',T35,F10.2,' DEG WEST OF GREENWICH',driv5530
     2  /,10X,'SUBSOLAR LATITUDE =',T35,F10.2,' NORTH OF EQUATOR',/,    driv5540
     3  10X,'SUBSOLAR LONGITUDE =',T35,F10.2,' WEST OF GREENWICH',/,    driv5550
     4  10X,'TIME (<0 IS UNDEF)=',T35,F10.3,' GREENWICH TIME',/,        driv5560
     5  10X,'PATH AZIMUTH =',T35,F10.3,' DEG EAST OF NORTH',/,          driv5570
     6  10X,'DAY OF YEAR =',T35,I10)                                    driv5580
      IF (IPARM.EQ.2) WRITE (IPR,1534)PARM1,PARM2,GMT,PSIPO,IDAY
1534  FORMAT(10X,'RELATIVE AZIMUTH =',T35,F10.3,' DEG EAST OF NORTH',/, driv5600
     1  10X,'SOLAR ZENITH =',T35,F10.3,' DEG ',/,                       driv5610
     2  10X,'TIME (<0 UNDEF) =',T35,F10.3,' GREENWICH TIME',/,          driv5620
     3  10X,'PATH AZIMUTH =',T35,F10.3,' DEG EAST OF NORTH',/,          driv5630
     4  10X,'DAY OF THE YEAR =',T35,I6)                                 driv5640
      IF (ISOURC.EQ.0) WRITE (IPR,1535)                                 driv5650
1535  FORMAT('0 EXTRATERRESTIAL SOURCE IS THE SUN')                     driv5660
      IF (ISOURC.EQ.1) WRITE (IPR,1536) ANGLEM                          driv5670
1536  FORMAT('0 EXTRATERRESTIAL SOURCE IS THE MOON, MOON PHASE ANGLE =',driv5680
     1  F10.2,' DEG')                                                   driv5690
      IF (IPH.EQ.0) WRITE (IPR,1538) G                                  driv5700
1538  FORMAT('0 H-G PHASE FUNCTION ,G=',F10.3)                          driv5710
      IF (IPH.EQ.1) WRITE (IPR,1540)                                    driv5720
1540  FORMAT('0 USER SUPPLIED PHASE FUNCTION')                          driv5730
      IF (IPH.EQ.2) WRITE (IPR,1542)                                    driv5740
1542  FORMAT('0 PHASE FUNCTION FROM MIE DATA BASE')                     driv5750
550   CONTINUE                                                          driv5760
C     V1 =FLOAT(INT(V1/5.0+0.1))*5.0                                    driv5770
C     V2 =FLOAT(INT(V2/5.0+0.1))*5.0                                    driv5780
C     TO AVOID THE DIFFICULTY FOR V1=0                                  driv5790
      ALAM1= 99999.98                                                   driv5800
C     IF(V1.GT.0.)ALAM1=10000./V1                                       driv5810
C     ALAM2=10000./V2                                                   driv5820
C     IF(DV.LT.5.)DV=5.                                                 driv5830
C     DV=FLOAT(INT(DV/5+0.1))*5.0                                       driv5840
C     WRITE (IPR,1555) V1,ALAM1,V2,ALAM2,DV                             driv5850
C1555 FORMAT('0 FREQUENCY RANGE '/,10X,' V1 = ',F12.1,' CM-1  (',       driv5860
C    1  F10.2,' MICROMETERS)',/,10X,' V2 = ',F12.1,' CM-1  (',F10.2,    driv5870
C    2  ' MICROMETERS)',/10X,' DV = ',F12.1,' CM-1')                    driv5880
      IF(.NOT.MODTRN)THEN                                               driv5890
```

```
          IV1=5*(IV1/5)                                                 driv5900
          IV2=5*((IV2+4)/5)                                             driv5910
          IDV=5+5*((IDV-5)/5)                                           driv5920
      ENDIF                                                             driv5930
      IF(IV2.LT.IV1+IDV)THEN                                            driv5940
          WRITE(IPR,'(/41H IV2 WAS LESS THAN IV1 + IDV AND HAS BEEN,    driv5950
     1        6H RESET,/)')                                             driv5960
          IV2=IV1+IDV                                                   driv5970
      ENDIF                                                             driv5980
CRZ       IF(MODTRN)THEN                                                driv5990
CRZ           IV1SAV=IV1                                                driv6000
CRZ           IV2SAV=IV2                                                driv6010
CRZ           IDVSAV=IDV                                                driv6020
CRZ       ENDIF                                                         driv6030
      IF(IV1.NE.0)ALAM1=10000./IV1                                      driv6040
      ALAM2=10000./IV2                                                  driv6050
      IF(IFWHM.LT.1)IFWHM=1                                             driv6060
      IF(IFWHM.GT.50)IFWHM=50                                           driv6070
      WRITE(IPR,'(17H0 FREQUENCY RANGE,/10X,8H   IV1 =,I10,8H CM-1  (,  driv6080
     1  F10.2,13H MICROMETERS),/10X,8H   IV2 =,I10,8H CM-1  (,F10.2,    driv6090
     2  13H MICROMETERS),/10X,8H   IDV =,I10,5H CM-1,/10X,8H IFWHM =,   driv6100
     3  I10,5H CM-1)')IV1,ALAM1,IV2,ALAM2,IDV,IFWHM                     driv6110
      WRITE(IP6,'(15HFREQUENCY RANGE,//10X,9HIV1     =,I11,8H CM-1  (,
     1  F7.2,13H MICROMETERS),/10X,9HIV2     =,I11,8H CM-1  (,F7.2,
     2  13H MICROMETERS),/10X,9HIDV     =,I11,5H CM-1,/10X,9HIFWHM   =,
     3  I11,5H CM-1,/10X,9HIFILTER =,I11)')
     4  IV1,ALAM1,IV2,ALAM2,IDV,IFWHM,IFILTER
C                                                                       driv6120
C*****LOAD ATMOSPHERIC PROFILE INTO /MODEL/                             driv6130
C                                                                       driv6140
      CALL STDMDL                                                       driv6150
C                                                                       driv6160
C    DEFINE COUNTER ITEST TO PREVENT ZENITH ANGLE QTHETA AND LAYER      driv6170
C    PATH LENGTH PL FROM BEING CHANGED DURING SOLAR CALCULATIONS        driv6180
555   DO 15 I=1,102                                                     driv6190
          DO 15 J=1,KMAX                                                driv6200
              WPATH(I,J)=0.0                                            driv6210
   15 WPATHS(I,J)=0.0                                                   driv6220
C                                                                       driv6230
      ITEST=0                                                           driv6240
C                                                                       driv6250
      IF (IMULT .EQ. 1) THEN                                            driv6260
          H1=ZM(1)                                                      driv6270
          H2=ZM(ML)                                                     driv6280
          ITYPE = 2                                                     driv6290
          ANGLE = 0.                                                    driv6300
          BETA = 0.                                                     driv6310
          RANGE =0.                                                     driv6320
          ISSGS = ISSGEO                                                driv6330
          ISSGEO = 0                                                    driv6340
C         CALL GEO (IERROR,BENDNG,MAXGEO)                               driv6350
          MSOFF=68                                                      driv6360
          CALL GEO (IERROR,BENDNG,MAXGEO,MSOFF)                         driv6370
          W15SV = W(15)                                                 driv6380
C                                                                       driv6390
C         W15SV  IS THE REL HUM FROM 0 TO SPACE                         driv6400
C         THIS REL HUM MAY BE DIFFERENT THAN THE PATH  REL HUM          driv6410
```

```
C         WHEN REL HUM ARE DIFFERENT THE ANSWER CAN CHANGE                   driv6420
C                                                                            driv6430
          ISSGEO = ISSGS                                                     driv6440
          IMSMX=IKMAX                                                        driv6450
          DO 35 N=1,IMSMX                                                    driv6460
C             PLST(N)=PL(N)                                                  driv6470
C             DO 35 K=1,KMAX                                                 driv6480
C35        WPMS(N,K)=WPATH(N,K)                                              driv6490
   35     PLST(N)=PL(N)                                                      driv6500
C                                                                            driv6510
          IF(IEMSCT.EQ.2)  THEN                                              driv6520
              CALL SSGEO(IERROR,IPH,IPARM,PARM1,PARM2,                       driv6530
C    1          PARM3,PARM4,PSIPO,G,MAXGEO)                                  driv6540
     1          PARM3,PARM4,PSIPO,G,MAXGEO,MSOFF)                            driv6550
              DO 30 N=1,IKMAX                                                driv6560
                  CSENSV(N) = ABS(CSZEN(N))                                  driv6570
                  IF(CSENSV(N) .LT. 0.0174) CSENSV(N) = 0.0174               driv6580
   30         CONTINUE                                                       driv6590
C             DO 45 N=1,ML                                                   driv6600
C                 DO 45 K=1,KMAX                                             driv6610
C                     WPMSS(N,K)=WPATHS(N,K)                                 driv6620
C  45         CONTINUE                                                       driv6630
          ENDIF                                                              driv6640
      ENDIF                                                                  driv6650
      H1     = H1S                                                           driv6660
      H2     = H2S                                                           driv6670
      ANGLE  = ANGLES                                                        driv6680
      RANGE  = RANGS                                                         driv6690
      BETA   = BETAS                                                         driv6700
      ITYPE  = ITYPES                                                        driv6710
      LEN    = LENS                                                          driv6720
C*****TRACE PATH THROUGH THE ATMOSPHERE AND CALCULATE ABSORBER AMOUNTS        driv6730
C                                                                            driv6740
      ISSGEO=0                                                               driv6750
      MSOFF=0                                                                driv6780
***** Save original value of SEA (false if earth not yet hit) ******
C
      SEAold = SEA
      CALL GEO(IERROR,BENDNG,MAXGEO,MSOFF)                                   driv6790
C
***** and set HIT true if the earth has been hit within FNDHMN: *****
      HIT = ((.NOT. SEAold) .AND. SEA)
      IF (HIT) THEN
          WRITE (IP6, '(/, 6HSEA AT, F7.2,
     +    31H K REPLACES BLACK BODY BOUNDARY,//,10X,9HUPWIND  =,F11.3,
     +    26H DEG EAST OF LINE OF SIGHT)') TBOUNDold, Psi
C         calculate geometry from point of view of the footprint
          IF (IEMSCTold .EQ. 1) Pr = Psi*d2r + pi
          IF ((IPARM .EQ. 0) .OR. (IPARM .EQ. 1)) THEN
                  ThetaO = PARM1
                  PhiO   = PARM2
                  ThetaS = PARM3
                  PhiS   = PARM4
                  CALL Foot(ThetaO,PhiO,ThetaS,PhiS,PsiPO,Beta,Psi)
              ELSE IF (IPARM .EQ. 2) THEN
                  Psi0   = PARM1
                  Del0   = PARM2
```

```
                  CALL SunFoot(Psi0,Del0,PsiP0,Beta,Psi)
              END IF
C             and issue new sky (and sun) cards in file 'TAPE5.SEA'
              CALL Card
          END IF
          IF ((SeaSwitch) .AND. (.NOT. Sea)) THEN
              WRITE (IP6, '(/, 13HTBOUND SET TO, F7.2,
         +    17H K FOR MARINE SKY)') TBOUND
          END IF
C
          CALL AERTMP                                                   driv6800
          IF(IMULT. NE. 1) W15SV = W(15)                                driv6810
C                                                                       driv6820
C     SAVE TEMPERATURE AND PATH INFO FOR LATER USE                      driv6830
C                                                                       driv6840
          IF(IMULT .EQ. 1)  THEN                                        driv6850
              DO 25 N=1,IKMAX                                           driv6860
   25         QTHETS(N) = QTHETA(N)                                     driv6870
          ENDIF                                                         driv6880
C                                                                       driv6890
          IF(IERROR.GT.0) GO TO 630                                     driv6900
          IF(IEMSCT.EQ.3 .AND. IERROR.EQ. -5) GO TO 557                 driv6910
          GO TO 558                                                     driv6920
  557     CONTINUE                                                      driv6930
          WRITE(IPR,1557)                                               driv6940
 1557     FORMAT('0 DIRECT PATH TO SUN INTERSECTS THE EARTH: SKIP TO ', driv6950
         1     'NEXT CASE')                                             driv6960
          GO TO 630                                                     driv6970
  558     CONTINUE                                                      driv6980
C                                                                       driv6990
          IF(IEMSCT.EQ.2)CALL SSGEO(IERROR,IPH,IPARM,PARM1,PARM2,PARM3, driv7000
C        1  PARM4,PSIPO,G,MAXGEO)                                       driv7010
         1  PARM4,PSIPO,G,MAXGEO,MSOFF)                                 driv7020
          W(15) = W15SV                                                 driv7030
C                                                                       driv7040
C         W15SV IS THE REL HUM  (FOR MULT SCAT THIS MAY BE DIFFERENT    driv7050
C         FROM PATH REL HUM)                                            driv7060
C                                                                       driv7070
C         THE SECOND CALL TO SSGEO IS TO GET THE CORRECT ANGLES FOR     driv7080
C         PHASE FUNCTIONS                                               driv7090
C                                                                       driv7100
C         SAVE SOLAR PATH INFORMATION                                   driv7110
C                                                                       driv7120
          IF(IERROR.GT.0) GO TO 630                                     driv7130
C                                                                       driv7140
          IF(IMULT.EQ.1) THEN                                           driv7150
              DO 60 IK = 1,IMSMX                                        driv7160
                  PL(IK)=PLST(IK)                                       driv7180
                  IF(IEMSCT.EQ.2) CSZEN(IK)=CSENSV(IK)                  driv7190
60            CONTINUE                                                  driv7200
                  DO 70 IK = 1,IKMAX
70                QTHETA(IK) = QTHETS(IK)                               driv7170
          ENDIF                                                         driv7210
C                                                                       driv7220
C*****LOAD AEROSOL EXTINCTION, ABSORPTION, AND ASYMMETRY COEFFICIENTS   driv7230
C                                                                       driv7240
          CALL EXABIN                                                   driv7250
```

```
C
C*****WRITE HEADER DATA TO TAPE 7
C
C560  WRITE(IPU,1110)MODEL,ITYPE,IEMSCT,IMULT,M1,M2,M3,
C    1  M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB
 560  WRITE(IPU,'(L1,I4,12I5,F8.3,F7.2)')MODTRN,MODEL
     1  ,ITYPE,IEMSCT,IMULT,M1,M2,M3,M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB
C     WRITE(IPR1,1110)MODEL,ITYPE,IEMSCT,IMULT,M1,M2,M3,
C    1  M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB
      WRITE(IPR1,'(L1,I4,12I5,F8.3,F7.2)')MODTRN,MODEL
     1  ,ITYPE,IEMSCT,IMULT,M1,M2,M3,M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB
      WRITE(IPU,1200)IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,
     1  RAINRT,GNDALT
      WRITE(IPR1,1200)IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,
     1  RAINRT,GNDALT
      WRITE(IPU,1210) CTHIK,CALT,CEXT,ISEED
      WRITE(IPR1,1210) CTHIK,CALT,CEXT,ISEED
      WRITE(IPU,1230)ZCVSA,ZTVSA,ZINVSA
      WRITE(IPR1,1230)ZCVSA,ZTVSA,ZINVSA
      WRITE(IPU,1255) ML,(HMODEL(I,7),I=1,5)
      WRITE(IPR1,1255) ML,(HMODEL(I,7),I=1,5)
1255  FORMAT( I5,18A4)
      IF(MODEL.NE.0)WRITE (IPU,1312) H1,H2,ANGLE,RANGE,BETA,RO,LEN
      IF(MODEL.NE.0)WRITE (IPR1,1312) H1,H2,ANGLE,RANGE,BETA,RO,LEN
      HMDLZ(8) = RANGE

      IF(MODEL.EQ.0) WRITE(IPU,1560)(HMDLZ(K),K=1,8)
      IF(MODEL.EQ.0) WRITE(IPR1,1560)(HMDLZ(K),K=1,8)
1560  FORMAT(3F10.3,5E10.3)
      WRITE(IPU,1320)  IPARM,IPH,IDAY,ISOURC
      WRITE(IPR1,1320) IPARM,IPH,IDAY,ISOURC
      WRITE(IPU,1322) PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
      WRITE(IPR1,1322)PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
C     WRITE(IPU,1400) V1,V2,DV
C     WRITE(IPR1,1400)V1,V2,DV
      WRITE(IPU,'(5I10)')IV1,IV2,IDV,IFWHM,IFILTER
      WRITE(IPR1,'(5I10)')IV1,IV2,IDV,IFWHM,IFILTER
C
CRZ   IRAIN=0
CRZ   IF(RAINRT.GT.0) IRAIN=1
CCC
CCC   CALCULATE EQUIVALENT LIQUID WATER CONSTANTS
CCC
      CALL EQULWC
      IF (SEA) THEN
              Msea = Msea + 1
              Done = (((IEMSCTold .EQ. 1) .AND. (Msea .EQ. 3))
     +          .OR. ((IEMSCTold .EQ. 2) .AND. (Msea .EQ. 4)))
              IF (Done) THEN
                      READ(IRD, 1600) IRPT
                  ELSE
                      READ(IRDS,1600) IRPT
              END IF
          ELSE
                  READ(IRD, 1600) IRPT
      END IF
1600  FORMAT(I5)
      WRITE(IPU,1600) IRPT
```

```
      WRITE(IPR1,1600)IRPT                                              driv7740
C                                                                       driv7750
      ground=.false.                                                    driv7760
      if(h2.le.zm(1))ground=.true.                                      driv7770
      IF (Msea .GT. -1)
     +    PRINT '(35H Driver: Calling TRANS for sea card, I2, 1H.)',Msea
      CALL TRANS(IPH,ISOURC,IDAY,ANGLEM,ground)
C                                                                       driv7790
C     TRANS RETURNS IRPT = -4 IF THE SPECTRAL RANGE EXTENDS BEYOND THE  driv7800
C     BAND MODEL TAPE.  IN THIS CASE, A LOWTRAN 7 CALCULATION IS        driv7810
C     PERFORMED FOR THE SHORT WAVELENGTHS AND THEN THE ORIGINAL INPUT   driv7820
C     IS RESTORED.   (NOTE:  THIS FEATURE WAS COMMENTED OUT.)
C                                                                       driv7840
*************  Reset the parameters to their original values  ********
*************  from before TAPE5.SEA was introduced, provided ********
*************  all cards from TAPE5.SEA have been read. **************
C
      IF (Done) THEN
          CLOSE (IRDS, STATUS='KEEP')
          Sea     = .FALSE.
          SeaOld  = .FALSE.
          Hit     = .FALSE.
          Msea    = -1
          ITYPE   = ITYPEold
          IEMSCT  = IEMSCTold
          IMULT   = IMULTold
          TBOUND  = TBOUNDold
          SALB    = SALBold
      END IF
C
**********************************************************************
C*****WRITE END OF FILE ON TAPE 7                                       driv8050
630   IF(IERROR .GT. 0) THEN                                            driv8060
          READ(IRD,1600,END=900) IRPT                                   driv8070
          WRITE(IPU,1600) IRPT                                          driv8080
          WRITE(IPR1,1600)IRPT                                          driv8090
      ENDIF                                                             driv8100
      WRITE(IPU,1620)                                                   driv8110
      WRITE(IPR1,1620)                                                  driv8120
1620  FORMAT(' -9999.')                                                 driv8130
C                                                                       driv8140
      WRITE(IPR,1630)IRPT                                               driv8150
1630  FORMAT('0 CARD 5 *****',I5)                                       driv8160
      IF (IRPT.EQ.0) GO TO 900                                          driv8170
      IF (IRPT.EQ.4) GO TO 400                                          driv8180
cssi  IF (IRPT.GT.1 .AND. IEMSCT.EQ.3) THEN                             driv8190
cssi  PRINTg1,'/!! ERROR IN INPUT IEMSCT EQ 3 IRPT GT 1!'               driv8200
cssi          STOP                                                      driv8210
cssi  ENDIF                                                             driv8220
      IF (IRPT.GT.4) GO TO 900                                          driv8230
      GO TO (100,900,300,400), IRPT                                     driv8240
  900 Call Timer(Iend)
c     to find how long the calculation took:
      WRITE (ITM, 1880) (FLOAT(Iend)-FLOAT(Istart))/100.
 1880 FORMAT ('Elapsed time (sec) for the last run was ', F8.2)
      STOP                                                              driv8250
      END                                                               driv8260
```

APPENDIX C
MODIFIED SUBROUTINE "TRANS"

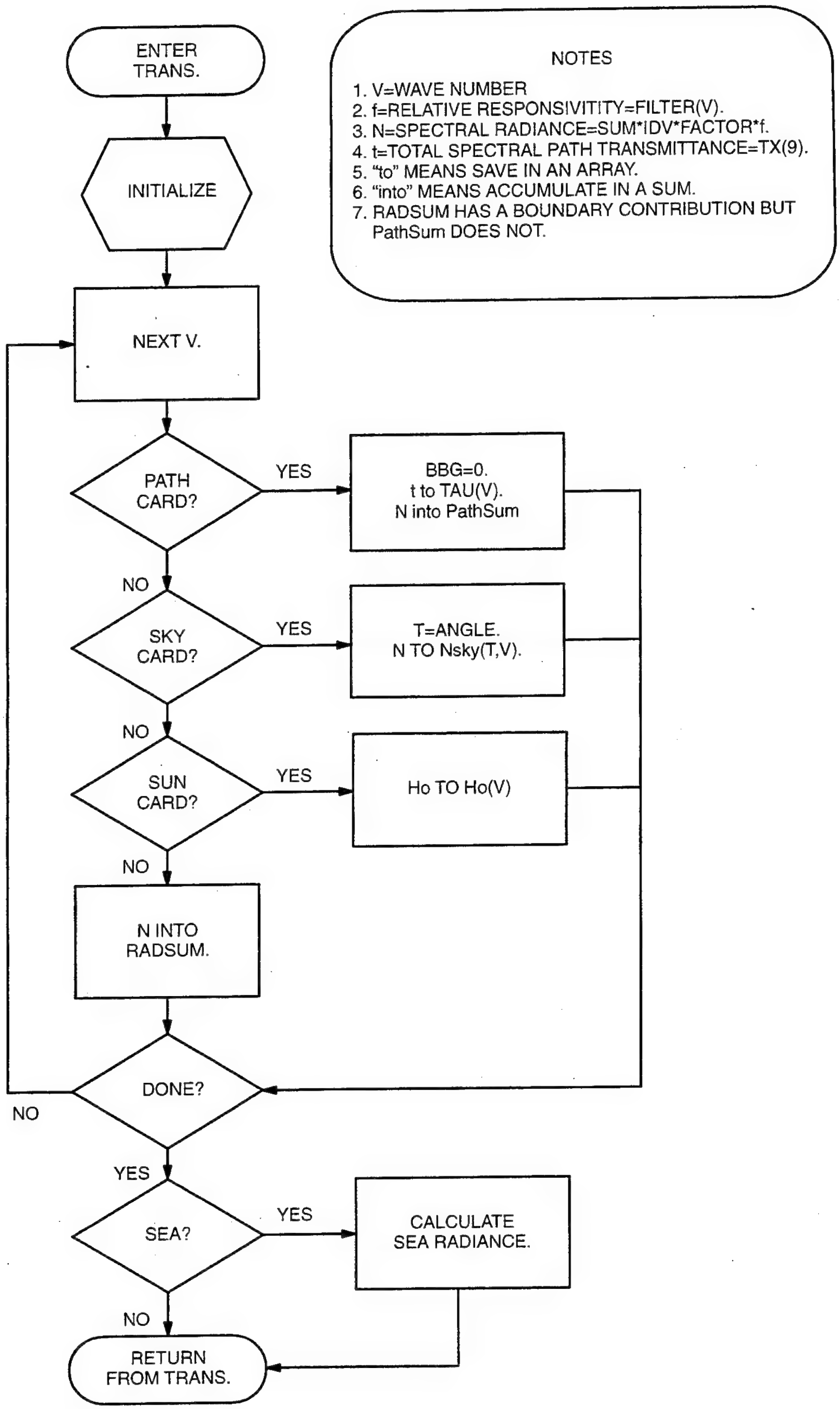


Figure C-1. Flowchart for modified subroutine "TRANS."

```
      SUBROUTINE TRANS(IPH,ISOURC,IDAY,ANGLEM,ground)
C
C     CALCULATES TRANSMITTANCE AND RADIANCE VALUES BETWEEN IV1 AND IV2
C     FOR A GIVEN ATMOSPHERIC SLANT PATH
      parameter(nbins=99,iprint=50,maxv=50000)
      real WGT(nbins),SLIT(56,nbins)
      LOGICAL IVTEST,loop0,ground,transm,modtrn
      COMMON RELHUM(34),WHNO3(34),ICH(4),VH(17),TX(63),W(63),IMSMX,
     1  WPATH(102,63),TBBY(102),PATM(102),NSPEC,KPOINT(12),
     2  ABSC(5,47),EXTC(5,47),ASYM(5,47),VX0(47),AWCCON(5)
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,
     +              ITR,Isky,Isun,Ipath
      COMMON/CARD1/MODEL,ITYPE,IEMSCT,M1,M2,M3,IM,NOPRNT,TBOUND,SALB,
     1  MODTRN
      COMMON /CARD2/ IHAZE,ISEASN,IVULCN,ICSTL,ICIR,IVSA,VIS,WSS,WHH,
     1    RAINRT
      COMMON/CARD3/H1,H2,ANGLE,RANGE,BETA,REE,LEN
      COMMON/CARD4/IV1,IV2,IDV,IFWHM,IFILTER
      COMMON/CNSTNS/PIX,CA,DEG,GCAIR,BIGNUM,BIGEXP
      COMMON/CNTRL/KMAX,M,IKMAX,NL,ML,IKLO,ISSGEO,IMULT
      COMMON/SOLS/AH1(68),ARH(68),
     1  WPATHS(102,63),PA(68),PRX(68),ATHETA(35),ADBETA(35),LJ(69),
     2  JTURN,ANGSUN,CSZEN(68),TBBYS(102,12),PATMS(102,12)
      COMMON/SRAD/TEB1,TEB2SV
      COMMON/MSRD/TLE(34),COSBAR(34),OMEGA0(68),UPF(10,34),DNF(10,34),
     1  TAER(34),ASYIK(68),ASYDM(68),STRN(0:34),DMOLS(68),DSTRN(0:68),
     2  FDNSRT,FDNTRT,TAUT(34),UMF(34),DMF(34),UMFS(34),DMFS(34)
      COMMON/ICLL/ICALL,FPHS,FALB,FORBIT
      PARAMETER (Kr = 216, Kv = 400)
      COMMON /Filters/ FLIST(5,6),
     +                 FILTER1(45), BB1(Kr), FILTER2(54), BB2(Kr),
     +                 FILTER3(39), BB3(Kr), FILTER4(47), BB4(Kr),
     +                 FILTER5(101),BB5(Kr), FILTER6(75), BB6(Kr)
      COMMON/Sea/ Sea,Hit,Msea,TBOUNDold,IEMSCTold
      COMMON/Geometry/ To,Po,Tr,Pr
      COMMON/Constants/pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      DIMENSION Tau(Kv), SkyN(3,Kv), Ho(Kv), Tsky(3), Rsky(3)
      LOGICAL Sea, PathCard, SkyCard, LastSky, SunCard, Hit
      REAL Npath, Nsky, Nvsky, Nsea, Nsun, Ntotal, Nbb, infinity, No
      T0 = 273.15
      common /solar/lsame
      logical lsame
c
c     Initialize slit function array
      DO 10 I = 1,56
          DO 10 J = 1,nbins
   10 SLIT(I,J) =0.
c
c     Initialize radiance minimum and maximum parameters
      RADMIN=bignum
      RADMAX=0.
c
c     Initialize ground emissivity (one minus ground albedo)
      EMISS=1.-SALB
C
C     Store the number of path layers in ikmx
      IKMX=IKMAX
```

```
c
c     Initialize integrated absorption, radiance, solar irradiance and
c     transmitted solar irradiance sums
      SUMA=0.
      RADSUM=0.
      SSOL=0.
      STSOL=0.
      PathSum  = 0.
      PathCard = .FALSE.
      SkyCard  = .FALSE.
      LastSky  = .FALSE.
      SunCard  = .FALSE.
      IF (Sea) THEN
          IF (Msea .EQ. 0) THEN
                  PathCard = .TRUE.
              ELSE IF ((Msea .GE. 1) .AND. (Msea .LE. 3)) THEN
                  SkyCard  = .TRUE.
              ELSE IF (Msea .EQ. 4) THEN
                  SunCard  = .TRUE.
          END IF
          IF (Msea .EQ. 3) THEN
              LastSky  = .TRUE.
          END IF
      END IF
      IF (SkyCard) Tsky(Msea) = ANGLE*d2r
      Istore = 0
c
c     Initialize integration weighting factor
      FACTOR=.5
c
c     Initialize icount, used to determine when header must be printed
      ICOUNT=iprint
c
c     Do not perform a MODTRAN calculation if all sources are continuum
cssi  IF(IV1.GE.22655)modtrn=.false.
      IF(IV1.GE.22681)modtrn=.false.
      IF(modtrn)THEN
C
C         WHEN THE band model or line-by-line option is used, call
C         routine "bmdata" to INITIALIZE PARAMETERS AND TO SET THE
C         FREQUENCY STEP SIZE "IDVX" TO THE BAND WIDTH (1 CM-1).
          IDV5=5
          CALL bmdata(IV1,IFWHM,IDVX,IKMX,MXFREQ)
          IWIDM1=IFWHM/IDVX-1
          IV=5*((IV1-IWIDM1)/5)
          IF(IV.LT.0)IV=0
          IVX=IV-IDVX
          IV=IV-5
          IVXMAX=IV2+IWIDM1
      ELSE
          IDV5=IDV
          IDVX=IDV5
          IWIDM1=0
          IV=IV1-IDV5
          IVX=IV
          IVXMAX=IV2+IWIDM1
          IF(IVXMAX.GT.maxv)IVXMAX=maxv
```

```
          IF(IDV.LT.5)IDV=5
      ENDIF
      IWRITE=IV1+IWIDM1
      IWIDTH=IWIDM1+1
C
C     PERFORM TRIANGULAR SLIT INITIALIZATION.  TRANSMITTANCES AT A
C     GIVEN FREQUENCY CONTRIBUTE TO 2*IWIDTH-1 TRIANGULAR SLITS.
C     THESE CONTRIBUTIONS ARE STORED IN ARRAY SLIT.  WGT IS THE
C     NORMALIZED WEIGHT USED TO DEFINE THE TRIANGLE.
      NWGT=2*IWIDTH
      WNORM=1./(IWIDTH*IWIDTH)
      DO 20 I=1,IWIDTH
          WGT(I)=I*WNORM
   20 WGT(NWGT-I)=wgt(i)
      NWGT=NWGT-1
      NWGTM1=NWGT-1
c
c     Initialize ICALL (= 0 for initial call to subroutine source)
      ICALL=0
c
c     Initialize transm (.true. for transmittance only calculations)
      transm=.true.
      IF(IEMSCT.EQ.1 .OR. IEMSCT.EQ.2)transm=.false.
c
c     Print headers
      IF(IEMSCT.EQ.0)THEN
          WRITE(IPU,'(46H \FREQ   TOTAL     H2O      CO2+ OZONE     TRACE,
     1      49H  N2 CON  H2O CON MOL SCAT AER-HYD HNO3   AER-HYD)')
          WRITE(IP7,'(46H \FREQ   TOTAL     H2O      CO2+ OZONE     TRACE,
     1      49H  N2 CON  H2O CON MOL SCAT AER-HYD HNO3   AER-HYD)')
          WRITE(IPR1,'(45H  \FREQ  H2O      O3       CO2     CO       CH4,
     1      47H      N2O     O2      NH3      NO      NO2      SO2,/
     2      55H  \1/CM  TRANS   TRANS    TRANS   TRANS    TRANS    TRANS,
     3      39H  TRANS  TRANS    TRANS   TRANS     TRANS)')
          WRITE(IP8, '(45H  \FREQ  H2O      O3       CO2     CO       CH4,
     1      47H      N2O     O2      NH3      NO      NO2      SO2,/
     2      55H  \1/CM  TRANS   TRANS    TRANS   TRANS    TRANS    TRANS,
     3      39H  TRANS  TRANS    TRANS   TRANS     TRANS)')
      ELSE IF(IEMSCT .EQ. 3) THEN
          WRITE (IPU,'(32H \FREQ    TRANS      SOL TR  SOLAR)')
          WRITE (IP7,'(2H \, T25,
     +                40HIRRADIANCE (W M-2) PASSED THROUGH FILTER,
     +                I2)') IFILTER
          WRITE (IP7,'(32H \FREQ    TRANS      SOL TR  SOLAR)')
      ELSE IF (IEMSCT .EQ. 1) THEN
          WRITE(IPU,'(45H \FREQ   TRANS     ATMOS. RAD., T88,
     +                18H- LOG TOTAL TRANS.)')
          WRITE(IP7,'(2H \, T25,
     +                43HRADIANCE (W M-2 SR-1) PASSED THROUGH FILTER,
     +                I2)') IFILTER
          WRITE(IP7,'(30H \FREQ   TRANS     ATMOS. RAD., T88,
     +                18H- LOG TOTAL TRANS.)')
      ELSE IF (IEMSCT .EQ. 2) THEN
          WRITE(IPU,'(42H \FREQ   TRANS     ATMOS    PATH      SINGLE,
     1      28H    GROUND DIRECT   TOTAL RAD)')
          WRITE(IP7,'(2H \, T25,
     +                43HRADIANCE (W M-2 SR-1) PASSED THROUGH FILTER,
```

```
     +             I2)') IFILTER
          WRITE(IP7,'(42H \FREQ   TRANS     ATMOS   PATH     SINGLE,
     1      28H   GROUND DIRECT   TOTAL RAD, T88,
     +             18H- LOG TOTAL TRANS.)')
      END IF
      If (PathCard) then
              WRITE(IPath,'(1H\, T25,
     +        52HRADIANCE (W M-2 SR-1 (CM-1)-1) PASSED THROUGH FILTER,
     +        I2,/,1H\,/,40H\  V      T      f     Npath*f   INTEGRAL,
     +        /,1H\)') Ifilter
          Else if (LastSky) then
              WRITE(Isky,'(1H\, T25,
     +        52HRADIANCE (W M-2 SR-1 (CM-1)-1) PASSED THROUGH FILTER,
     +        I2,/,1H\,/,40H\  V      T      f    Nsky*T*f   INTEGRAL,
     +        22H   Nsea*T*f   INTEGRAL,/,1H\)') Ifilter
          Else if (SunCard) then
              WRITE(Isun,'(1H\, T25,
     +        52HRADIANCE (W M-2 SR-1 (CM-1)-1) PASSED THROUGH FILTER,
     +        I2,/,1H\,/,40H\  V      T      f    Nsun*T*f   INTEGRAL,
     +        /,1H\)') Ifilter
      End If
      IF(NOPRNT.EQ.-1)THEN
          IF(IMULT.EQ.1)THEN
              WRITE(IPR1,'(37H      \V   ALT1    UFLX       UFLXS,
     1          50H      DFLX       DFLXS      DIRS         TRANS)')
              WRITE(IP8, '(37H      \V   ALT1    UFLX       UFLXS,
     1          50H      DFLX       DFLXS      DIRS         TRANS)')
          ELSE
              IF(IEMSCT.GT.0)WRITE(IPR1,'(23H        \V   ALT1   ALT2,
     1          30H    B(V,T)     DTAU        TAU)')
                             WRITE(IP8, '(23H        \V   ALT1   ALT2,
     1          30H    B(V,T)     DTAU        TAU)')
          ENDIF
      ENDIF
c
c     Initialize layer loop variables
      loop0=.true.
      call loop(loop0,iv,ivx,ikmx,mxfreq,summs,transm,iph,
     1  sumssr,ivtest,unif,trace,sumv,isourc,iday,anglem,frac)
      loop0=.false.
c
c     END INITIALIZATION, BEGIN OF FREQUENCY LOOP
c
c     "IVX" IS THE FREQUENCY AT WHICH TRANSMITTANCE WILL BE CALCULATED.
c     DURING THE FIRST PASS, "IVX" AND "IV" MUST BE EQUAL.
   30 IVX=IVX+IDVX
          IF(IV.LT.IVX)THEN
              IV=IV+IDV5
              IVTEST=.TRUE.
          ELSE
              IVTEST=.FALSE.
          ENDIF
c
c         SET INTERPOLATION FRACTION.
          FRAC=FLOAT(IV-IVX)/IDV5
          IF(ICOUNT.EQ.iprint)THEN
c
```

```
c           Reinitialize counter and print header                        tras1590
            ICOUNT=0                                                     tras1600
            IF(IEMSCT.EQ.0)THEN                                          tras1610
                WRITE(IPR,'(1H1,/33H   FREQ WAVELENGTH  TOTAL      H2O,tras1620
     1            47H     CO2+      OZONE     TRACE  N2 CONT  H2O CONT, tras1630
     2            47H MOL SCAT  AER-HYD  HNO3    AER-HYD  INTEGRATED, tras1640
     3            //43H   1/CM  MICRONS     TRANS     TRANS     TRANS,  tras1650
     4            44H    TRANS     TRANS    TRANS    TRANS     TRANS,   tras1660
     5            40H     TRANS    TRANS    ABS      ABSORPTION,/)')     tras1670
            ELSEIF(IEMSCT.EQ.1)THEN                                      tras1680
                WRITE(IPR,'(1H1,20X,28HRADIANCE(WATTS/CM2-STER-XXX),     tras1690
     1            /8H0    FREQ,T10,6HWAVLEN,T19,14HATMOS RADIANCE,       tras1700
     2            T39,9H INTEGRAL,T49,5HTOTAL,/2X,6H(CM-1),              tras1710
     3            T10,7H(MICRN),T19,6H(CM-1),T29,7H(MICRN),              tras1720
     4            T39,6H(CM-1),T49,5HTRANS,/)')                          tras1730
            ELSEIF(IEMSCT.EQ.3)THEN                                      tras1740
                WRITE(IPR,'(1H1,22X,27HIRRADIANCE (WATTS/CM2-XXXX),      tras1750
     1            /7H0  FREQ,T11,6HWAVLEN,T23,11HTRANSMITTED,            tras1760
     2            T45,5HSOLAR,T61,10HINTEGRATED,T80,5HTOTAL,             tras1770
     3            /2X,6H(CM-1),T10,7H(MICRN),T20,6H(CM-1),               tras1780
     4            T30,7H(MICRN),T40,6H(CM-1),T50,7H(MICRN),              tras1790
     5            T60,6HTRANS.,T70,5HSOLAR,T80,5HTRANS)')                tras1800
            ELSEIF(IMULT.EQ.0)THEN                                       tras1810
                WRITE(IPR,'(1H1,45X,28HRADIANCE(WATTS/CM2-STER-XXX),     tras1820
     1            /7H0  FREQ,T11,6HWAVLEN,T21,14HATMOS RADIANCE,         tras1830
     2            T41,14HPATH SCATTERED,T61,16HGROUND REFLECTED,         tras1840
     3            T85,5HTOTAL,T99,8HINTEGRAL,T110,5HTOTAL,               tras1850
     4            /2X,6H(CM-1),T10,7H(MICRN),T20,6H(CM-1),               tras1860
     5            T30,7H(MICRN),T40,6H(CM-1),T50,7H(MICRN),              tras1870
     6            T60,6H(CM-1),T70,7H(MICRN),T80,6H(CM-1),               tras1880
     7            T90,7H(MICRN),T100,6H(CM-1),T110,5HTRANS,/)')          tras1890
            ELSE                                                         tras1900
                WRITE(IPR,'(1H1,45X,28HRADIANCE(WATTS/CM2-STER-XXX),     tras1910
     1            //6H0 FREQ,T10,6HWAVLEN,T20,14HATMOS RADIANCE,T40,     tras1920
     2            4HPATH,19H SCATTERED RADIANCE,T69,                     tras1930
     3            25HGROUND REFLECTED RADIANCE,T100,14HTOTAL RADIANCE,tras1940
     4            T118,8HINTEGRAL,T127,5HTOTAL,/T45,5HTOffL,T59,         tras1950
     5            6HS SCAT,T75,5HTOTAL,T89,6HDIRECT,/1X,6H(CM-1),T9,     tras1960
     6            7H(MICRN),T19,6H(CM-1),T29,7H(MICRN),T39,6H(CM-1),     tras1970
     7            T49,7H(MICRN),T59,6H(CM-1),T69,6H(CM-1),T79,           tras1980
     8            7H(MICRN),T89,6H(CM-1),T99,6H(CM-1),T109,7H(MICRN),    tras1990
     9            T119,6H(CM-1),T127,5HTRANS,/)')                        tras2000
            ENDIF                                                        tras2010
        ENDIF                                                            tras2020
c                                                                        tras2030
c       Determine layer loop maximum                                     tras2040
        IF(transm)THEN                                                   tras2050
c                                                                        tras2060
c           For transmission calculations, skip over layer loop in tratras2070
            IKMAX=1                                                      tras2080
        ELSEIF(IMULT.EQ.1 .and. .not. lsame)THEN                         tras2090
c                                                                        tras2100
C           FOR MULTIPLE SCATTERING SET IKMAX TO IMSMX                   tras2110
            IKMAX=IMSMX                                                  tras2120
        ELSE                                                             tras2130
c                                                                        tras2140
C           IF NOT MULTIPLE SCATTERING, RESET IKMAX TO ORIGINAL VALUE tras2150
```

```
               IKMAX=IKMX                                                tras2160
           ENDIF                                                         tras2170
           SUMV=0.                                                       tras2180
C                                                                        tras2190
C          Initialize transmission array                                 tras2200
           TX(1)=1.                                                      tras2210
           TX(2)=1.                                                      tras2220
           TX(3)=1.                                                      tras2230
           DO 40 K=4,KMAX                                                tras2240
   40      TX(K)=0.                                                      tras2250
           call loop(loop0,iv,ivx,ikmx,mxfreq,summs,transm,              tras2260
     1       iph,sumssr,ivtest,unif,trace,sumv,isourc,iday,anglem,frac)  tras2270
C                                                                        tras2280
C          THE PARAMETERS "UNIF", "TRACE", "SUMV", "SUMSSR", "SUMMS"     tras2290
C          AND "TEB1" ARE TEMPORARILY STORED IN "TX" SO THAT THEIR       tras2300
C          CONVOLUTION OVER THE TRIANGULAR SLIT CAN BE CALCULATED.       tras2310
           TX(2)=UNIF                                                    tras2320
           TX(3)=TRACE                                                   tras2330
           TX(8)=SUMV                                                    tras2340
           TX(12)=SUMSSR                                                 tras2350
           TX(13)=SUMMS                                                  tras2360
           TX(14)=TEB1                                                   tras2370
           DO 60 K=2,56                                                  tras2380
               IP1=NWGT                                                  tras2390
               DO 50 I=NWGTM1,1,-1                                       tras2400
                   SLIT(K,IP1)=SLIT(K,I)+WGT(IP1)*tx(k)                  tras2410
   50          IP1=I                                                     tras2420
               SLIT(K,1)=WGT(1)*tx(k)                                    tras2430
   60      TX(K)=SLIT(K,NWGT)                                            tras2440
C                                                                        tras2450
C          CHECK IF VALUES ARE TO BE PRINTED                             tras2460
           IF(IVX.LT.IWRITE)GOTO30                                       tras2470
           IWRITE=IWRITE+IDV                                             tras2480
           IF(IWRITE.GT.IVXMAX)FACTOR=.5                                 tras2490
           ICOUNT=ICOUNT+1                                               tras2500
C                                                                        tran2510
C          RENORMALIZE IF TRIANGULAR SLIT EXTENDS TO NEGATIVE FREQUENCIEStras2520
           IF(IVX.LT.NWGTM1)THEN                                         tras2530
               store=1.-.5*(NWGTM1-IVX)*(NWGTM1-IVX+1)*WNORM             tras2540
               DO 70 K=2,56                                              tras2550
   70          TX(K)=TX(K)/store                                         tras2560
           ENDIF                                                         tras2570
           UNIF=TX(2)                                                    tras2580
           TRACE=TX(3)                                                   tras2590
           SUMV=TX(8)                                                    tras2600
           SUMSSR=TX(12)                                                 tras2610
           SUMMS=TX(13)                                                  tras2620
           TEB1=TX(14)                                                   tras2630
           V=FLOAT(IVX-IWIDM1)                                           tras2640
           ALAM=1.0E+04/(V+.000001)                                      tras2650
           Istore = Istore + 1
           Width = IDV*FACTOR
           f = Filter(V,Ifilter)
           SUMA=SUMA+(1.0-TX(9))*f*Width
           ALTX9=BIGNUM                                                  tras2670
           IF(TX(9).GT.0.)ALTX9=-LOG(TX(9))                              tras2680
           GOTO(80,90,90,100),IEMSCT+1                                   tras2690
```

```
C                                                                               tras2700
C         TRANSMITTANCE ONLY                                                    tras2710
   80     TX(10)=1.-TX(10)                                                      tras2720
          TX(7)=TX(7)*TX(16)                                                    tras2730
          WRITE(IPR,'(F8.0,F8.3,11F9.4,F12.3)')V,ALAM,TX(9),TX(17),             tras2740
     1      UNIF,TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),SUMAtras2750
          WRITE(IPR1,'(F7.0,11F8.4,1PE10.3)')V,TX(17),TX(31),TX(36),            tras2760
     1      TX(44),TX(46),TX(47),TX(50),TX(52),TX(54),TX(55),TX(56)             tras2770
          WRITE(IP8, '(F7.0,11F8.4,1PE10.3)')V,TX(17),TX(31),TX(36),
     1      TX(44),TX(46),TX(47),TX(50),TX(52),TX(54),TX(55),TX(56)
          WRITE(IPU,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,                tras2780
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9            tras2790
          WRITE(IP7,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9
          GOTO110                                                               tras2800
C                                                                               tras2810
C         ATMOSPHERIC RADIANCE INCLUDING EMISSION OF BOUNDARY                   tras2820
C         ATTENUATED BY TOTAL TRANSMISSION                                      tras2830
C                                                                               tras2840
C         CALCULATE THERMAL RADIANCE CONTRIBUTION OF BOUNDARY AND               tras2850
C         ADD THE SCATTERED CONTRIBUTION TO THE THERMAL RADIANCE                tras2860
C         IF THE PATH INTERSECTS THE SURFACE                                    tras2870
   90     IF ((TBOUND.LE.0.) .OR. (PathCard)) THEN
              BBG = 0.                                                          tras2890
          ELSE                                                                  tras2900
              BBG=BBFN(TBOUND,V)*TX(9)*EMISS                                    tras2910
              IF(IMULT.EQ.1 .AND. ground) THEN
                  BBG=BBG+SALB*FDNTRT*TX(9)/PI                                  tras2920
              END IF
          ENDIF                                                                 tras2930
C                                                                               tras2940
C         ADD THERMAL BOUNDARY AND MULTIPLE SCATTERED RADIANCE                  tras2950
          SUMV=(SUMV+BBG)*f
          SUMVV=SUMV                                                            tras2970
          IF (V.GT.0.) THEN
              SUMV=(1.0E+08/V**2)*SUMV              !  W m-2 sr-1 (cm-1)-1
          END IF
          IF(IEMSCT.EQ.1)THEN                                                   tras2990
              RADSUM=RADSUM + SUMV*Width
              WRITE(IPR,'(F8.0,F8.3,1P3E10.2,0PF9.4)')                          tras3010
     1          V,ALAM,SUMV,SUMVV,RADSUM,TX(9)                                  tras3020
              WRITE(IPU,'(F7.0,F8.4,1PE15.8,T96,E10.3)')                        tras3030
     1          V,TX(9),SUMV,ALTX9                                              tras3040
              WRITE(IP7,'(F7.0,F8.4,1PE15.8,T96,E10.3)')
     1          V,TX(9),SUMV,ALTX9
          WRITE(IPr1,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,               tras3050
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9            tras3060
          WRITE(IP8, '(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9
              SUMT=SUMV                                                         tras3070
              SUMTT=SUMVV                                                       tras3080
          ELSE                                                                  tras3090
C                                                                               tras3100
C             SOLAR SCATTERED RADIANCE                                          tras3110
              CALL SOURCE(V,ISOURC,IDAY,ANGLEM,SS)                              tras3120
C                                                                               tras3130
C             MULTIPLY SUMSSR BY THE EXTRATERRESTRIAL SOURCE STRENGTH SStras3140
```

```
          SUMSSS=SUMSSR*SS                                                tras3150
C                                                                         tras3160
C         CALCULATE TOTAL SINGLE SCATTERED + MULTIPLE SCATTERED           tras3170
C         SOLAR RADIANCE FOR EACH FREQUENCY [W/CM2-STER-MICROMETER]       tras3180
          SUMSSR=SUMSSS+SUMMS                                             tras3190
          store=0.                                                        tras3200
          if(v.gt.0.)store=1.e8/v**2      ! [W m-2 sr-1 (cm-1)-1]
          SUMS=store*SUMSSR                                               tras3220
          SUMSSS=store*SUMSSS                                             tras3230
C                                                                         tras3240
C         RFLSOL IS GROUND-REFLECTED DIRECT SOURCE RADIANCE AND           tras3250
          RFLSOL=0.                                                       tras3260
          RFLS=0.                                                         tras3270
          RFLSS=0.                                                        tras3280
          RFLSSS=0.                                                       tras3290
          IF(ground .AND. TEB1.GT.0)THEN                                  tras3300
              IF(ANGSUN.GE.0.)RFLSSS=SS*TEB1*SALB*COS(ANGSUN*CA)/PI       tras3310
              RFLSOL=RFLSSS                                               tras3320
              IF(IMULT.EQ.1)RFLSOL=RFLSOL+SALB*FDNSRT*TX(9)/PI            tras3330
              RFLS=STORE*RFLSOL                                           tras3340
              RFLSS=STORE*RFLSSS                                          tras3350
          ENDIF                                                           tras3360
          SUMT=SUMV+(SUMS+RFLS)*f
          SUMTT=SUMVV+(SUMSSR+RFLSOL)*f
          RADSUM=RADSUM + SUMT*Width
          IF (IMULT.NE.1) THEN                                            tras3400
                  WRITE(IPR,'(F8.0,F8.3,1P9E10.2,0PF9.4)')                tras3410
     1             V,ALAM,SUMV,SUMVV,SUMS,SUMSSR,RFLS,RFLSOL,             tras3420
     2            SUMT,SUMTT,RADSUM,TX(9)                                 tras3430
              ELSE                                                        tras3440
                  WRITE(IPR,'(F7.0,F8.3,1P11E10.2,0PF7.4)')               tras3450
     1            V,ALAM,SUMV,SUMVV,SUMS,SUMSSR,SUMSSS,RFLS,              tras3460
     2            RFLSOL,RFLSS,SUMT,SUMTT,RADSUM,TX(9)                    tras3470
          END IF                                                          tras3480
          WRITE(IPU,'(F7.0,F8.4,1P6E9.2,0P2F8.4,T96,1PE10.3)')V,          tras3490
     1      TX(9),SUMV,SUMS,SUMSSS,RFLS,RFLSS,SUMT,TEB1,TEB2SV,ALTX9tras3500
          WRITE(IP7,'(F7.0,F8.4,1P6E9.2,0P2F8.4,T96,1PE10.3)')V,
     1      TX(9),SUMV,SUMS,SUMSSS,RFLS,RFLSS,SUMT,TEB1,TEB2SV,ALTX9
      WRITE(IPr1,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,             tras3510
     1  TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9          tras3520
      WRITE(IP8, '(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,
     1  TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9
      END IF                                                              tras3530
      IF (PathCard) THEN
              Tau(Istore) = TX(9)
              PathSum = PathSum + SUMT*Width
              Write(Ipath, '(I5,2F7.3,2(1PE11.3))')
     +                             V, TX(9), f, SUMT, PathSum
      END IF
      IF (SkyCard) SkyN(Msea,Istore) = SUMT
C
      GO TO 110                                                           tras3540
C                                                                         tras3550
C     DIRECTLY TRANSMITTED SOLAR IRRADIANCE [WATTS/(CM2 MICROMETER)]tras3560
  100 CALL SOURCE(V,ISOURC,IDAY,ANGLEM,SOLIL)                             tras3570
      SOLIV=0.                                                            tras3580
      IF(V.GT.0.)SOLIV=SOLIL*1.E+8/V**2    !  [W m-2 sr-1 (cm-1)-1]
```

```
          TSOLIV=SOLIV*TX(9)*f
          IF (SunCard) then
              Ho(Istore) = TSOLIV
          END IF
          TSOLIL=SOLIL*TX(9)*f
          STSOL=STSOL+TSOLIV*Width
          SSOL=SSOL+SOLIV*Width
          WRITE(IPR,'(F8.0,F8.3,1P6E10.2,0PF9.4)')                        tras3640
     1      V,ALAM,TSOLIV,TSOLIL,SOLIV,SOLIL,STSOL,SSOL,TX(9)             tras3650
          WRITE(IPU,'(F7.0,F8.4,1P2E9.2,T96,E10.3)')                      tras3660
     1      V,TX(9),TSOLIV,SOLIV,ALTX9                                    tras3670
          WRITE(IP7,'(F7.0,F8.4,1P2E9.2,T96,E10.3)')
     1      V,TX(9),TSOLIV,SOLIV,ALTX9
          WRITE(IPr1,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,         tras3680
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9      tras3690
          WRITE(IP8, '(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9
          SUMT=TSOLIV                                                     tras3700
          RADSUM=STSOL                                                    tras3710
  110     IF(IEMSCT.NE.0)THEN                                             tras3720
              IF(SUMT.GE.RADMAX)THEN                                      tras3730
                  VRMAX=V                                                 tras3740
                  RADMAX=SUMT                                             tras3750
              ENDIF                                                       tras3760
              IF(SUMT.LE.RADMIN)THEN                                      tras3770
                  VRMIN=V                                                 tras3780
                  RADMIN=SUMT                                             tras3790
              ENDIF                                                       tras3800
          ENDIF                                                           tras3810
          FACTOR=1.                                                       tras3820
      IF(IWRITE.LE.IVXMAX)GOTO30                                          tras3830
C                                                                         tras3840
C     END OF FREQUENCY LOOP                                               tras3850
C                                                                         tras3860
      IVX=INT(V+.5)                                                       tras3870
C
      IF (IFILTER .EQ. 0) THEN
              Sumf = IVX - IV1
          ELSE IF ((1 .LE. IFILTER) .AND. (IFILTER .LE. 6)) THEN
              Sumf = FLIST(5, IFILTER)
      END IF

      IF ((.NOT. Sea) .AND. ((IEMSCT .EQ. 1) .OR. (IEMSCT .EQ. 2))) THEN
          IF (IFILTER .EQ. 0) THEN
                  V1 = FLOAT (IV1)
                  V2 = FLOAT (IVX)
                  dV = FLOAT (IDVX)
                  CALL RtoT (V1, V2, dV, RADSUM/1.E4, BBTEMP)
              ELSE IF ((IFILTER .GE. 1) .AND. (IFILTER .LE. 6)) THEN
                  CALL Planck (RADSUM/1.E4, IFILTER, BBTEMP)
          END IF
      END IF

      IF (Sea) THEN
          IF (PathCard) THEN
                  Npath      = PathSum
                  PathTrans = 1.-SUMA/Sumf
```

```
                PathRange = RANGE
                PathAngle = ANGLE
            ELSE IF (LastSky) THEN
                DO I = 1, Istore
                    DO K = 1, 3
                        Rsky(K) = SkyN(K,I)
                    END DO
                    CALL Fit(Tsky,Rsky,3,a,b)
                    V = IV1 + (I - 1.)*IDV
                    f = FILTER(V,Ifilter)
                    IF ((I .EQ. 1) .OR. (I .EQ. Istore)) THEN
                            Width = IDV/2.
                        ELSE
                            Width = IDV
                    END IF
                    Nbb = BBFN(TBOUNDold,V)*f*1E8/V**2
                    CALL Sky(Tr,Pr,WSS,a,b,V,BoverA,ev,Nvsky)
                    Nsky = Nsky +  Nvsky*Width*Tau(I)
                    Nsea = Nsea + ev*Nbb*Width*Tau(I)
                    Write(Isky, '(I5, 2F7.3, 4(1PE11.3))')
     +                   V, Tau(I), f, Nvsky*Tau(I), Nsky,
     +                   ev*Nbb*Tau(I), Nsea
                END DO
            ELSE IF (SunCard) THEN
                DO I = 1, Istore
                    V = IV1 + (I - 1.)*IDV
                    f = FILTER(V, Ifilter)
                    IF ((I .EQ. 1) .OR. (I .EQ. Istore)) THEN
                            Width = IDV/2.
                        ELSE
                            Width = IDV
                    END IF
                    CALL Sun(Tr,Pr,WSS,To,Po,V,sum4)
                    No = Ho(I)*sum4/(4.*pi*epsilon**2*BoverA)
                    Nsun  = Nsun + No*Width*Tau(I)
                    Write(Isun, '(I5,2F7.3,2(1PE11.3))')
     +                 V, Tau(I), f, No*Tau(I), Nsun
                END DO
        END IF
        Ntotal = Npath + Nsea + Nsky + Nsun
        IF (IFILTER .EQ. 0) THEN
                V1 = FLOAT (IV1)
                V2 = FLOAT (IVX)
                dV = FLOAT (IDVX)
                CALL RtoT (V1, V2, dV, Ntotal/1.E4, TotalT)
            ELSE IF ((IFILTER .GE. 1) .AND. (IFILTER .LE. 6)) THEN
                CALL Planck (Ntotal/1.E4, IFILTER, TotalT)
        END IF
    END IF
C
    IF (.NOT. Sea) THEN
        WRITE(IPR,'(26HINTEGRATED ABSORPTION FROM,I5,3H TO,I5,          tras3880
     +      7H CM-1 =,F10.2,5H CM-1,/23HAVERAGE TRANSMITTANCE =,        tras3890
     +      F6.4,/)') IV1,IVX,SUMA,1.-SUMA/Sumf
        WRITE(IP6,'(
     +     /24HINTEGRATED ABSORPTION  =, F10.2,
     +      10H CM-1 FROM, I5, 3H TO, I5, 5H CM-1,
```

```
     +        /24HAVERAGE TRANSMITTANCE  =, F12.4)')
     +         SUMA,IV1,IVX,1.-SUMA/Sumf
          IF (IEMSCT .EQ. 0) THEN
                WRITE(IP4, '(T13,F7.2,F8.3,F10.3,F8.3)')
     +               (90.-ANGLE)*pi/180.*1.E3,
     +               ANGLE, RANGE, 1.-SUMA/Sumf
            ELSE IF ((IEMSCT .EQ. 1) .OR. (IEMSCT .EQ. 2)) THEN
                WRITE(IPR,'(22 HINTEGRATED RADIANCE =,1PE11.3,
     +               10H WATTS M-2,7H STER-1,
     +              /22H MINIMUM RADIANCE     =,E11.3,10H WATTS M-2,
     +               19H STER-1 (CM-1)-1 AT,0PF11.1,5H CM-1,
     +               /8H MAXIMUM,14H RADIANCE    =,1PE11.3,
     +               29H WATTS M-2 STER-1 (CM-1)-1 AT,0PF11.1,5H CM-1,
     +               23H BOUNDARY TEMPERATURE =, F11.2,2H K,
     +              /22H BOUNDARY EMISSIVITY =,F12.3)')
     +               RADSUM,RADMIN,VRMIN,RADMAX,VRMAX,TBOUND,EMISS     tras4020
                WRITE(IP6,'(
     +               /24HMAXIMUM RADIANCE         =, 1PE11.3,
     +                23H W M-2 SR-1 (CM-1)-1 AT,  0PF8.1, 5H CM-1,
     +               /24HMINIMUM RADIANCE         =, 1PE11.3,
     +                23H W M-2 SR-1 (CM-1)-1 AT,  0PF8.1, 5H CM-1,
     +               /24HBOUNDARY TEMPERATURE     =, F11.2, 2H K,
     +               /24HBOUNDARY EMISSIVITY      =, F12.3,
     +               /24HFILTERED RADIANCE        =, 1PE11.3,
     +                11H W M-2 SR-1,
     +               /24HBLACKBODY TEMPERATURE  =, 0PF11.1, 2H C)')
     +                RADMAX,VRMAX,RADMIN,VRMIN,TBOUND,EMISS,
     +                RADSUM, BBTEMP - T0
               WRITE(IP4,'(T13,F7.2,F8.3,F10.3,F8.3,5(1PE10.3),
     +                                                     0PF8.1)')
     +               (90.-ANGLE)*pi/180.*1.E3, ANGLE, RANGE,
     +               1.-SUMA/Sumf, RADSUM, Nsea, Nsky, Nsun,
     +               RADSUM, BBTEMP-T0
            ELSE
                WRITE(IPR,'(24H INTEGRATED IRRADIANCE =,1PE11.3,        tras3920
     +               10H WATTS M-2,/24H MINIMUM IRRADIANCE     =,E11.3, tras3930
     +               13H WATTS M-2 AT,0PF11.1,5H CM-1,/10H  MAXIMUM ,   tras3940
     +               14H IRRADIANCE  =,1PE11.3,
     +               23H WATTS M-2  (CM-1)-1 AT,0PF11.1,5H CM-1)')
     +               RADSUM,RADMIN,VRMIN,RADMAX,VRMAX                   tras3960
                WRITE(IP6,'(
     +               24HINTEGRATED IRRADIANCE  =, 1PE11.3, 6H W M-2,
     +              /24HMINIMUM IRRADIANCE      =,   E11.3,
     +               18H W M-2 (CM-1)-1 AT, 0PF8.1, 5H CM-1,
     +              /24HMAXIMUM IRRADIANCE      =, 1PE11.3,
     +               18H W M-2 (CM-1)-1 AT, 0PF8.1, 5H CM-1)')
     +               RADSUM,RADMIN,VRMIN,RADMAX,VRMAX
          END IF
      END IF
C
      IF (((LastSky) .AND. (IEMSCTold .EQ. 1)) .OR. (SunCard)) THEN
          WRITE(IP6, '(/, 24HRECEIVED RADIANCE VALUES,
     +   //, T10,24H PATH TO FOOTPRINT
     =,   F10.5, 11H W M-2 SR-1,
     +        T56,12H (AV. TRANS.,                F7.4,  1H),
     +    /, T10,24H SEA EMISSION           =,    F10.5, 11H W M-2 SR-1,
     +    /, T10,24H SKY REFLECTION         =,    F10.5, 11H W M-2 SR-1,
```

```
+    /, T10,24H SUN GLINT              =,    F10.5, 11H W M-2 SR-1,
+   //, T10,24H TOTAL RADIANCE         =,    F10.5, 11H W M-2 SR-1,
+    /, T10,24H BLACK BODY TEMP.       =,    F10.1,  2H C )')
+        Npath, PathTrans, Nsea, Nsky, Nsun, Ntotal, TotalT-T0
     WRITE(IP4, '(T13,F7.2,F8.3,F10.3,F8.3,5(1PE10.3),0PF8.1)')
+        (90.-PathAngle)*pi/180.*1.E3, PathAngle, PathRange,
+         PathTrans, Npath, Nsea, Nsky, Nsun, Ntotal, TotalT-T0
     Npath = 0.
     Nsea  = 0.
     Nsky  = 0.
     Nsun  = 0.
 END IF
C
 RETURN                                                            tras4100
 END                                                               tras4110
```

APPENDIX D
SOURCE CODE FOR NEW *SeaRad* SUBROUTINES

```
******************************* MOD22.FOR *******************************
*                                                                       *
*     New version of Cox-Munk routines with integration over sea        *
*     slopes and interpolation between three sky angles for estimation *
*     of incident sky radiance.                                         *
*                                                                       *
*     Last revised: July 14, 1995.                                      *
*                                                                       *
*************************************************************************

      SUBROUTINE Sky(Tr,Pr,W,a,b,v,BoverA,e,Nsky)
      REAL Nsky
CU    USES rho

c     Outputs:
c         Calculates (1) the normalization factor "BoverA" in the
c         denominator of the interaction probability, and spectral
c         values for (2) the effective emmisivity "e" of the ocean
c         surface, and (3) the sky radiance "Nsky" [W m-2 sr-1 (cm-1)-1]
c         reflected from the ocean surface.

c    Inputs:
c         The receiver spherical coordinates [rad] are (Tr,Pr). The
c         wind speed is W [m s-1]. v [cm-1] is the wavenumber. a and b are
c         coefficients of a least squares fit such that Ns, the spectral
c         sky radiance [W m-2 sr-1 (cm-1)-1] incident on the ocean
c         at zenith angle Ts [rad] , is given by

c                        Ns(Ts,v) = 1./[a(v) - b(v)*Ts**2].

c    Last revision:
c         January 27, 1995.

      COMMON/Constants/pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      REAL infinity, Ns
      if (W .ge. .01) then
c             use the Cox-Munk standard deviation for a real sea
              Su = sqrt(3.16E-3*W)
              Sc = sqrt(3.E-3 + 1.92E-3*W)
          else
c             use a delta function for an ideal calm sea
              Su = .01
              Sc = .01
      end if
      p0  = 1./(2.*pi*Su*Sc)
      Sav = (Su + Sc)/2.
      N   = 2
      M   = 7
      Smx = N*2.303*Sav
      dS  = Smx/M
      Ar  = sin(Tr)*cos(Pr)
      Br  = sin(Tr)*sin(Pr)
      Cr  = cos(Tr)

      sum1 = 0.
      sum2 = 0.
      sum3 = 0.
```

```
      do Sx = -Smx, Smx, dS
          Symx = sqrt(abs(Smx**2 - Sx**2))
          do Sy = -Symx, Symx, dS
c             For each position (Sx,Sy) in slope space:

c             calculate the occurrence probability density p:
              arg = ((Sx/Su)**2 + (Sy/Sc)**2)/2.
              if ((arg) .ge. log(p0/delta)) then
                      p = 0.
                  else
                      p = p0*exp(-arg)
              end if

c             calculate omega, the angle of incidence and Ts,
c             the zenith angle of the source ray.
              dd = Sx**2 + Sy**2
              f0 = - Ar*Sx - Br*Sy +Cr
              vv = f0/sqrt(1. + dd)
              if ((onem .le. vv) .and. (vv .le. onep)) then
                      omega = 0.
                  else if ((-onep .le. vv) .and. (vv .le. -onem)) then
                      omega = pi
                  else
                      omega = acos(vv)
              end if
              uu = (- 2.*Ar*Sx - 2.*Br*Sy + Cr*(1. - dd))/(1. + dd)
              if ((onem .le. uu) .and. (uu .le. onep)) then
                      Ts = 0.
                  else if ((-onep .le. uu) .and. (uu .le. -onem)) then
                      Ts = pi
                  else
                      Ts = acos(uu)
              end if

c             interpolate for Ns(Ts),
              Ns = 1./(a - b*(Ts**2))

c             define integrands,
              f1 = f0*p
              f2 = rho(omega,v)*f1
              f3 = Ns*f2

c             and accumulate integrals over all slopes.
              if (omega .le. pi/2.) then
                  sum1 = f1 + sum1
                  sum2 = f2 + sum2
                  if (Ts .le. pi/2.) sum3 = f3 + sum3
              end if
          end do
      end do
      sum1 = sum1*dS**2
      sum2 = sum2*dS**2
      sum3 = sum3*dS**2

      BoverA = sum1
      e      = 1. - sum2/sum1
```

```
      Nsky    = sum3/sum1

      return
      END

      SUBROUTINE Sun(Tr,Pr,W,To,Po,v,sum4)
CU    USES rho

c     Outputs:
c         Calculates a spectral solar reflectivity "sum4" for the
c         ocean surface apart from a normalization factor of
c         (4.*"BoverA") or (4.*"sum1").

c    Inputs:
c         The receiver spherical coordinates [rad] are (Tr,Pr). The
c         wind speed is W [m s-1]. The spherical coordinates [rad]
c         of the solar center are (To,Po). v [cm-1] is the wavenumber.

c     Note:
c         The larger the value of M, the y coordinate step size, the
c         more precise and slower the sum.  For fixed M precision
c         improves with wind speed.  For W = 1 m s-1 and M = 5, the
c         precision is better than 1.5 % around the center of the
c         glint pattern until the receiver zenith angle exceeds 89.5
c         degrees.

c     Bug:
c         Divides by zero when the sun is on the zenith.

c     Last Revision:
c         January 27, 1995.

      COMMON/Constants/pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      REAL infinity

c     Find the rectangular receiver coordinates
      Ar = sin(Tr)*cos(Pr)
      Br = sin(Tr)*sin(Pr)
      Cr = cos(Tr)

c     Find the Cox-Munk wind dependent slope standard deviations
      if (W .ge. .01) then
c             use the Cox-Munk standard deviation for a real sea
              Su = sqrt(3.16E-3*W)
              Sc = sqrt(3.E-3 + 1.92E-3*W)
          else
c             use a delta function for an ideal calm sea
              Su = .01
              Sc = .01
      end if
      p0  = 1./(2.*pi*Su*Sc)

      M = 5
      N = 2*M + 1
      sum  = 0.
      dY   = 2.*epsilon/N
      do I = 1, N
```

```
            Y    = epsilon - (I - 0.5)*dY
            Xmax = sqrt(epsilon**2 - Y**2)
            K    = int(2.*Xmax/dY + onem*0.5)
            dX   = 2.*Xmax/K
            do J = 1, K
                X  = Xmax - (J - 0.5)*dX

c               For each position (X,Y) (rectangular coordinates with
c               respect to the solar center) on the solar disk,

c               Find the spherical source coordinates:
                Ts = To - Y
                Ps = Po - X/sin(To)
                if (Ts .gt. pi/2.*onep) then
                    print *, "Error from 'Sun': Part of solar disk"
                    print *, "                  is below horizon."
                    return
                endif

c               Find the the rectangular source coordinates:
                As = sin(Ts)*cos(Ps)
                Bs = sin(Ts)*sin(Ps)
                Cs = cos(Ts)

c               Find the slopes (Sx,Sy) for a specular reflection from
c               source (Ts,Ps) to receiver (Tr,Pr):
                if (abs(As + Ar) .le. delta) then
                        Sx = 0.
                    else if ((Cs + Cr) .le. delta) then
                        Sx = sign(infinity, -(As + Ar))
                    else
                        Sx = - (As + Ar)/(Cs + Cr)                      (A12)
                end if
                if (abs(Bs + Br) .le. delta) then
                        Sy = 0.
                    else if ((Cs + Cr) .le. delta) then
                        Sy = sign(infinity, -(Bs + Br))
                    else
                        Sy = - (Bs + Br)/(Cs + Cr)                      (A13)
                end if

c               Find the Cox-Munk occurrence probability density:
                arg = ((Sx/Su)**2 + (Sy/Sc)**2)/2.
                if ((arg) .ge. log(p0/delta)) then
                        p = 0.
                    else
                        p = p0*exp(-arg)
                end if

c               Find the angle of incidence (omega) for the specular
c               reflection:
                dd = (1. + As*Ar + Bs*Br + Cs*Cr)/2.                    (A14)
                if (dd .le. delta) dd = 0.
                ss = sqrt(dd)                                           (A14)
                if ((onem .le. ss) .and. (ss .le. onep)) then
                        omega = 0.
                    else if ((-onep .le. ss) .and. (ss .le. -onem)) then
```

```
                omega = pi
            else
                omega = acos(ss)                                    (A14)
        end if

c       Find the facet tilt (Tn) for the specular reflection:
        Tn = atan(sqrt(Sx**2 + Sy**2))                              (A6)

c       Integrate:
        sum = rho(omega,v)/(cos(Tn)**4)*p*dX + sum                  (32)

    end do
end do
sum4 = sum*dY
return
END

SUBROUTINE Fit(x,y,n,a,b)
DIMENSION x(*),y(*)

c   Given (x,y) pairs in the data arrays x(i) and y(i), where
c   1 <= i <= n, performs a least sqares fit of these data to
c   the equation

c                  y = 1/(a - b*x**2)

c   and returns the values of a and b.

c   Last revised:  March 13, 1995.

DOUBLE PRECISION nn, bb, cc(4)
c                 where cc(1:4) = c01, c21, c20, c40.
nn = FLOAT(n)

do i = 1, n
    if (y(i) .eq. 0.) then
        a = 7.E5
        b = 0.
        return
    end if
end do

do i = 1, 4
    cc(i) = 0.d0
end do

do i = 1, n
    cc(1) = cc(1) + 1./y(i)
    cc(2) = cc(2) + x(i)**2/y(i)
    cc(3) = cc(3) + x(i)**2
    cc(4) = cc(4) + x(i)**4
end do

bb = (nn*cc(2) - cc(3)*cc(1))/(nn*cc(4) - cc(3)**2)
a  = (cc(1) - cc(3)*bb)/nn
b  = - bb
```

```
      END

      SUBROUTINE Foot(ThetaO, PhiO, ThetaS, PhiS, PsiPO, Beta, Psi)
CU    USES Angle, Side
      COMMON /Constants/ Spi,Sr2d,Sd2r,epsilon,delta,onem,onep,infinity
      COMMON /Geometry/ To,Po,Tr,Pr
      COMMON /Card2/ IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,W,WHH,
     +               RAINRT
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,
     +              ITR,Ipath,Isky,Isun
      COMMON /Sea/ Sea, Hit, Msea, TBOUNDold, IEMSCTold
      REAL infinity
C
************************************************************************
*                                                                      *
*     This routine calculates zenith angles and azimuthal angles from  *
*     the footprint, defined as the location where a hit has just      *
*     occurred.                                                        *
*                                                                      *
*     All the arguments are inputs, and all are angles in degrees:     *
*         ThetaO and PhiO are the observer latitude and longitude.     *
*         ThetaS and PhiS are the solar latitude and longitude.        *
*         PsiPO is the path azimuth (+ E of N) seen by the observer.   *
*         Beta is the angle subtended at the center of the earth       *
*             between the observer and the footprint.                  *
*         PsiW is the wind azimuth (+E of N) seen by the observer.     *
*                                                                      *
*     The outputs are To, Po, and Pr, angles in radians passed         *
*     through the common block "Geometry":                             *
*         To is the zenith angle of the center of the sun              *
*             from the footprint.                                      *
*         Po is the azimuth (+ W. of PsiW) of the center of the sun    *
*             from the footprint.                                      *
*         Pr is the azimuth (+ W. of PsiW) receiver as seen            *
*             from the footprint.                                      *
*         Note: Tr has been calculated in DPFNMN and is used           *
*               in this subroutine only for printing to "OUT".         *
*                                                                      *
*     Last revision: June 15, 1995.                                    *
*                                                                      *
************************************************************************

      DOUBLE PRECISION DThetaO, DPhiO, DThetaS, DPhiS, DPsiPO, DBeta,
     +                 DPsiW, DThetaF, DPhiF, Pi, Side, Angle, DTo, DPo

      Pi  = 4.*DATAN(1.)
      D2R = Pi/180.
      R2D = REAL(180./Pi)

C     First, convert to radians and increase precision:

      DThetaS = DBLE(ThetaS)*D2R
      DPhiS   = DBLE(PhiS)*D2R
      DThetaO = DBLE(ThetaO)*D2R
      DPhiO   = DBLE(PhiO)*D2R
      DPsiPO  = DBLE(PsiPO)*D2R
      DBeta   = DBLE(Beta)*D2R
```

```
      DPsiW    = DBLE(Psi+PsiPO)*D2R

C     then use the geometry of three spherical triangles connecting
C     the north pole, the observor, the sun, and the footprint:

      DThetaF = Pi/2. - Side(Pi/2.-DThetaO, -DPsiPO, DBeta)

      IF (DPsiPO .GE. Pi) THEN
              DPhiF   = DPhiO + Angle(Pi/2.-DThetaO,DBeta,Pi/2.-DThetaF)
          ELSE
              DPhiF   = DPhiO - Angle(Pi/2.-DThetaO,DBeta,Pi/2.-DThetaF)
      END IF

      DTo = Side(Pi/2.-DThetaS, DPhiS-DPhiF, Pi/2.-DThetaF)
      To  = REAL(DTo)

      IF (DPhiS .GE. DPhiO) THEN
              DPo = DPsiW + Angle(Pi/2.-DThetaF, Pi/2.-DThetaS, DTo)
          ELSE
              DPo = DPsiW - Angle(Pi/2.-DThetaF, Pi/2.-DThetaS, DTo)
      END IF
      Po = REAL(DPo)

      IF (DPhiF .GE. DPhiO) THEN
              DPr = DPsiW - Angle(Pi/2.-DThetaF, Pi/2.-DthetaO, DBeta)
          ELSE
              DPr = DPsiW + Angle(Pi/2.-DThetaF, Pi/2.-DthetaO, DBeta)
      END IF
      Pr = REAL(DPr)

C     Calculate specular slope (merely for print-out, not used for
C     further calculations):

C     Find the rectangular receiver coordinates,
      Ar = sin(Tr)*cos(Pr)
      Br = sin(Tr)*sin(Pr)
      Cr = cos(Tr)

C     Find the the rectangular source coordinates for the solar center,
      Ao = sin(To)*cos(Po)
      Bo = sin(To)*sin(Po)
      Co = cos(To)

C     Find the Cox-Munk wind dependent slope variances
      if (W .ge. .01) then
C             use the Cox-Munk variance for a real sea
              Vu = 0.000 + 3.16E-3*W
              Vc = 0.003 + 1.92E-3*W
          else
C             use a delta function for an ideal calm sea
              Vu = .0001
              Vc = .0001
      end if
      p0 = 1./(2.*pi*sqrt(Vu*Vc))

C     Find the slopes (Sxo,Syo) for a specular reflection from
C     source (To,Po) to receiver (Tr,Pr),
```

```
      if (abs(Ao + Ar) .le. delta) then
              Sxo = 0.
          else if ((Co + Cr) .le. delta) then
              Sxo = sign(infinity, -(Ao + Ar))
          else
              Sxo = - (Ao + Ar)/(Co + Cr)                                      (A12)
      end if
      if (abs(Bo + Br) .le. delta) then
              Syo = 0.
          else if ((Co + Cr) .le. delta) then
              Syo = sign(infinity, -(Bo + Br))
          else
              Syo = - (Bo + Br)/(Co + Cr)                                      (A13)
      end if

C     Calculate the Cox-Munk tilt and slope:
      arg = Sxo**2/Vu + Syo**2/Vc
      p  = p0*exp(-0.5*arg)
      Tn = atan(sqrt(Sxo**2 + Syo**2))

C     and print to "OUT":

      WRITE (IP6,1000)
      WRITE (IP6,1010) DBeta*R2D,DPsiPO*R2D,AMOD(DPsiW*R2D,360.)
      IF ((IEMSCTold) .EQ. 2) THEN
          WRITE (IP6,1020) DThetaO*R2D,DPhiO*R2D,DThetaF*R2D,DPhiF*R2D,
     +                     DThetaS*R2D,DPhiS*R2D
      END IF
      WRITE (IP6,1030)
      WRITE (IP6,1040) Tr*R2D,AMOD(Pr*R2D,360.)
      IF ((IEMSCTold) .EQ. 2) THEN
          WRITE (IP6,1050) To*R2D,AMOD(Po*R2D,360.),Sr2d*Tn,sqrt(arg),p
      END IF
C
1000  format(/,'SUMMARY OF OBSERVATION GEOMETRY'/)
1010  format (10X,'BETA                     =',F10.5,
     +          ' DEG',/,
     +        10X,'PATH AZIMUTH             =',F10.3,
     +            ' DEG EAST OF NORTH',/,
     +        10X,'WIND AZIMUTH             =',F10.3,
     +            ' DEG EAST OF NORTH',\)
1020  format (10X,'RECEIVER LATITUDE        =',F10.3,
     +            ' NORTH OF EQUATOR',/,
     +        10X,'RECEIVER LONGITUDE       =',F10.3,
     +            ' WEST OF GREENWICH',/,
     +        10X,'FOOTPRINT LATITUDE       =',F10.3,
     +            ' NORTH OF EQUATOR',/,
     +        10X,'FOOTPRINT LONGITUDE      =',F10.3,
     +            ' WEST OF GREENWICH',/,
     +        10X,'SUBSOLAR LATITUDE        =',F10.3,
     +            ' DEG NORTH OF EQUATOR',/,
     +        10X,'SUBSOLAR LONGITUDE       =',F10.3,
     +            ' DEG WEST OF GREENWICH',//)
 1030 format(/,'VALUES SEEN FROM FOOTPRINT'/)
 1040 format (10X,'RECEIVER ZENITH ANGLE =',F10.3,
     +            ' DEG',/,
     +        10X,'RECEIVER AZIMUTH         =',F10.3,
```

```
     +              ' DEG WEST OF UP WIND')
 1050 format (10X,'SOLAR ZENITH ANGLE    =',F10.3,
     +              ' DEG',/,
     +          10X,'SOLAR AZIMUTH         =',F10.3,
     +              ' DEG WEST OF UP WIND',/,
     +          10X,'SOLAR SPECULAR TILT   =',F10.3,
     +              ' DEG (', F6.2, ' SIGMA, PROB =',1PE10.3,')')

      return
      END

      SUBROUTINE SunFoot(Psi0, Del0, PsiPO, Beta, Psi)
CU    USES Angle, Side
      COMMON /Constants/ Spi,Sr2d,Sd2r,epsilon,delta,onem,onep,infinity
      COMMON /Geometry/ To,Po,Tr,Pr
      COMMON /Card2/ IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,W,WHH,
     +               RAINRT
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,
     +              ITR,Ipath,Isky,Isun
      COMMON /Sea/ Sea, Hit, Msea, TBOUNDold, IEMSCTold
      REAL infinity
C
***********************************************************************
*                                                                     *
*     This routine calculates zenith angles and azimuthal angles from *
*     the footprint, defined as the location where a hit has just     *
*     occurred, whenever the sun is involved. (PsiPO is not used in   *
*     the calculation; it's passed in only to be printed out.)        *
*                                                                     *
*     All the arguments are inputs, and all are angles in degrees:    *
*         Psi0 is the solar azimuth measured from the observor's      *
*             line-of-sight (+E of N).                                *
*         Del0 is the solar zenith angle as seen by the observor.     *
*         Beta is the angle subtended at the center of the earth      *
*             between the observor and the footprint.                 *
*         Psi is the wind azimuth measured from the observor's        *
*             line-of-sight (+E of N).                                *
*             (Psi is ASSUMED to be the same at the footprint.)       *
*                                                                     *
*     The outputs are To, Po, and Pr, angles in radians passed        *
*     through the common block "Geometry":                           *
*         To is the zenith angle of the center of the sun             *
*             from the footprint.                                     *
*         Po is the azimuth (+ W of PsiW) of the center of the sun    *
*             from the footprint.                                     *
*         Pr is the azimuth (+ W of PsiW) receiver as seen            *
*             from the footprint.                                     *
*         Note: Tr has been calculated in DPFNMN and is used          *
*               in this subroutine only for printing to "OUT".        *
*                                                                     *
*     Last revision: June 14, 1995.                                   *
*                                                                     *
***********************************************************************

      DOUBLE PRECISION DPsi0, DDel0, DBeta, Pi, Side, Angle, DTo, DPo

      Pi  = 4.*DATAN(1.)
```

```
      D2R = Pi/180.
      R2D = REAL(180./Pi)

c     First, convert to radians and increase precision:

      DPsi0 = DBLE(Psi0)*D2R
      DDel0 = DBLE(Del0)*D2R
      DBeta = DBLE(Beta)*D2R
      DPsi  = DBLE(Psi)*D2R

c     then use the geometry of the spherical triangle connecting
c     the observor, the sun, and the footprint:

      DTo = Side(DBeta, DPsi0, DDel0)
      To  = REAL(DTo)

      DPr = Pi + DPsi
      Pr  = REAL(DPr)

      If (DPsi0 .GT. 0.) then
              DPo = DPr + Angle(DTo, DDel0, DBeta)
          Else if (DPsi0 .EQ. 0.) then
              DPo = DPr + Pi
          Else
              DPo = DPr - Angle(DTo, DDel0, DBeta)
      End If
      Po  = REAL(DPo)

c     Calculate specular slope (calculations from now on merely for
c     print-out, not for further calculations):

c     Find the rectangular receiver coordinates,
      Ar = sin(Tr)*cos(Pr)
      Br = sin(Tr)*sin(Pr)
      Cr = cos(Tr)

c     Find the the rectangular source coordinates for the solar center,
      Ao = sin(To)*cos(Po)
      Bo = sin(To)*sin(Po)
      Co = cos(To)

c     Find the Cox-Munk wind dependent slope variances
      if (W .ge. .01) then
c             use the Cox-Munk variance for a real sea
              Vu = 0.000 + 3.16E-3*W
              Vc = 0.003 + 1.92E-3*W
          else
c             use a delta function for an ideal calm sea
              Vu = .0001
              Vc = .0001
      end if
      p0 = 1./(2.*pi*sqrt(Vu*Vc))

c     Find the slopes (Sxo,Syo) for a specular reflection from
c     source (To,Po) to receiver (Tr,Pr),
      if (abs(Ao + Ar) .le. delta) then
              Sxo = 0.
```

```
        else if ((Co + Cr) .le. delta) then
            Sxo = sign(infinity, -(Ao + Ar))
        else
            Sxo = - (Ao + Ar)/(Co + Cr)                              (A12)
    end if
    if (abs(Bo + Br) .le. delta) then
            Syo = 0.
        else if ((Co + Cr) .le. delta) then
            Syo = sign(infinity, -(Bo + Br))
        else
            Syo = - (Bo + Br)/(Co + Cr)                              (A13)
    end if

C     Calculate the Cox-Munk tilt and slope:
      arg = Sxo**2/Vu + Syo**2/Vc
      p  = p0*exp(-0.5*arg)
      Tn = atan(sqrt(Sxo**2 + Syo**2))

C     and print to "OUT":

      WRITE (IP6,2000)
      WRITE (IP6,2010) DBeta*R2D,PsiPO,AMOD((Psi+PsiPO), 360.)
      WRITE (IP6,2030)
      WRITE (IP6,2040) Tr*R2D,AMOD(Pr*R2D,360.)
      IF ((IEMSCTold) .EQ. 2) THEN
          WRITE (IP6,2050) To*R2D,AMOD(Po*R2D,360.),Sr2d*Tn,sqrt(arg),p
      END IF
C
 2000 format(/,'SUMMARY OF OBSERVATION GEOMETRY'/)
 2010 format (10X,'BETA                     =',F10.5,
     +              ' DEG',/,
     +         10X,'PATH AZIMUTH             =',F10.3,
     +              ' DEG EAST OF NORTH',/,
     +         10X,'WIND AZIMUTH             =',F10.3,
     +              ' DEG EAST OF NORTH',\)
 2030 format(/,'VALUES SEEN FROM FOOTPRINT'/)
 2040 format (10X,'RECEIVER ZENITH ANGLE =',F10.3,
     +              ' DEG',/,
     +         10X,'RECEIVER AZIMUTH      =',F10.3,
     +              ' DEG WEST OF UP WIND')
 2050 format (10X,'SOLAR ZENITH ANGLE    =',F10.3,
     +              ' DEG',/,
     +         10X,'SOLAR AZIMUTH         =',F10.3,
     +              ' DEG WEST OF UP WIND',/,
     +         10X,'SOLAR SPECULAR TILT   =',F10.3,
     +              ' DEG (', F6.2, ' SIGMA, PROB =',1PE10.3,')')

      return
      END

      SUBROUTINE Card
      COMMON /Card2/ IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,
     +               RAINRT
      COMMON /Card3/ H1,H2,ANGLE,RANGE,BETA,RE,LEN,Psi,SeaSwitch
      COMMON /Card3A1/ IPARM,IPH,IDAY,ISOURC
      COMMON /Card3A2/ PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,
```

```
     +              ITR,Ipath,Isky,Isun
      COMMON /Constants/ pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      COMMON /Geometry/ To,Po,Tr,Pr
      COMMON /Sea/ Sea,Hit,Msea,TBOUNDold,IEMSCTold
      REAL   infinity
      LOGICAL SeaSwitch

**********************************************************************
*                                                                    *
*     Issues new MODTRAN cards for the sea routines.                 *
*                                                                    *
*     When IEMSCTold = 1, no sun is involved, and three new sky      *
*     cards are issued to "TAPE5.SEA": one for Tmin, the minimum sky *
*     zenith angle expected at the current wind speed, one for       *
*     for Tmax, the maximum zenith angle expected, and one for Tav,  *
*     the sky zenith angle halfway between Tmax and Tmin.            *
*                                                                    *
*     When IEMSCTold = 2, the sun is involved, and after each new sky*
*     card the original cards 3A1 and 3A2 are reissued.  At the very *
*     end of the file there is one sun card.  Hence the number of new*
*     cards issued to 'TAPE5.SEA" is 10 when IEMSCTold = 2.          *
*                                                                    *
*     Last revised: February 28, 1995.                               *
*                                                                    *
**********************************************************************

      Irpt = 3

c     First, find the wind-dependent sky angles Tmin and Tmax:
      if (WSS .ge. .01) then
c             use the Cox-Munk standard deviation for a real sea
              Su = sqrt(3.16E-3*WSS)
              Sc = sqrt(3.E-3 + 1.92E-3*WSS)
          else
c             use a delta function for an ideal calm sea
              Su = .01
              Sc = .01
      end if
      S = 2.8
c         is the number of standard deviations to which the
c         wave slope integral will be carried; for S = 2.8
c         99 % of the volume under the distribution is captured.
      dT   = 2.02*(atan(S*amax1(Su,Sc)))
      Tmin = amax1(Tr - dT, 1.)
      Tmax = amin1(Tr + dT, d2r*89.)

c     Next, open TAPE5.SEA, the alternate file to TAPE5:
      open (Irds, file = 'Tape5.Sea', status = 'unknown')

c     then write the sky cards (IEMSCT = 2, ITYPE = 3):
      do Ts = Tmin, Tmax, onem*(Tmax-Tmin)/2.
          write (Irds, 150) Irpt
          write (Irds, 100) 0.,0.,Ts*r2d,0.,0.,0.,0,Psi,SeaSwitch
          if (IEMSCTold .eq. 2) then
              write (Irds, 400) IPARM,IPH,IDAY,ISOURC
              write (Irds, 500) PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,
     +                          ANGLEM,G
```

```
          end if
      end do

c     write the sun card (IEMSCT = 3, ITYPE = 3) if necessary:
      if (IEMSCTold .EQ. 2) then
          write (Irds, 150) Irpt
          write (Irds, 200) 0.,0.,To*r2d,IDAY,0.,0,0.
      end if

c     and finally
      rewind Irds
c     so it can be read from the beginning by the driver.

      return

  100 format (6F10.3,I5,F10.3,L5)
  150 format (I5)
  200 format (3F10.3,I5,5X,F10.3,I5,F10.3)
  400 format (4I5)
  500 format (8F10.3)

      END


****************************** FUNCTIONS ********************************
*                                                                        *
*     Latest revision:  May 5, 1994 for Side and Angle.                  *
*                                                                        *
**************************************************************************

      FUNCTION Side(a,C,b)
c     is the Law of Cosines for a spherical triangle with sides a, b,
c     and c and opposite angles A, B, C.  The three parameters are
c     the two sides a and b and the included angle C. Side is the
c     value of side c opposite the included angle C. Angles are in
c     radians.

      double precision a,C,b,Side
      Side = dacos(dcos(a)*dcos(b) + dsin(a)*dsin(b)*dcos(C))
      END

      FUNCTION Angle(a,c,b)
c     is the Law of Cosines for a spherical triangle with sides a, b,
c     and c and opposite angles A, B, C.  The three parameters are
c     the three sides.  Angle is the value of angle C opposite side
c     c, the middle parameter in the list. Angles are in radians.

      double precision pi,a,b,c,Angle,Arg,aa,bb
      pi = 4.*datan(1.)
      aa = dmin1(a, b)
      bb = dmax1(a, b)

      if (abs(aa) .le. 1.D-5) then
              Angle = dacos(dtan(aa)/dtan(bb))
              if (abs(bb) .lt. abs(c)) Angle = pi - Angle
      end if
```

```
      Arg = (dcos(c) - dcos(a)*dcos(b))/(dsin(a)*dsin(b))
      if (abs(Arg) .ge. (1 - 1.D-14)) then
              Angle = 0.
          else
              Angle = dacos(Arg)
      end if

      END

      FUNCTION Rho(Omega, V)
CU    USES SeaData
      COMMON /SeaIndex/ Alpha01(100), Alpha02(20),
     +                  Beta01 (100), Beta02 (20)

************************************************************************
*                                                                      *
*       Calculates reflectivity of sea water between 52.63 cm-1 and    *
*  25,000 cm-1 using equations (74) and (78) of Stratton, "Electro-    *
*  magnetic Theory", 1941, page 505, ff.  The sea water is assumed to  *
*  be a conducting medium;  both real and imaginary parts of the       *
*  index of water are used.  The notation of Stratton is adhered to    *
*  as closely as possible.                                             *
*                                                                      *
*       Omega is the angle of incidence in radians;  V is the wave-    *
*  number in cm-1;  Rho is the reflectivity.                           *
*                                                                      *
*  Last revision:  November 28, 1994                                   *
*                                                                      *
************************************************************************

C     The four-point interpolation functions are:
      WM(X) = (X - 1.)*(X - 2.)*X/6.
      W0(X) = (X - 1.)*(X - 2.)*(X + 1.)/2.
      W1(X) = (X + 1.)*(X - 2.)*X/2.
      W2(X) = (X + 1.)*(X - 1.)*X/6.

      IF ((Omega .LT. 0.) .OR. (Omega .GT. 1.57080)) THEN
C     Omega is out of bounds; set reflectivity to 0% and return:
          Rho = 0.
          RETURN
      END IF

      IF (V .EQ. 0.) THEN
C     set reflectivity to 100% and return:
          Rho = 1.
          RETURN
      END IF

      W = 1.E4/V

      IF (W .LT. 0.399999) THEN
C     print error message and return:
          Rho = 0.
          WRITE (6, 1000) V
          RETURN
      END IF
```

```
      IF (0.4 .LE. W .AND. W .LE. 19.8) THEN
C     use Lagrange 4 point interpolation on Block 01 data which
C     are at 0.2 um spacing between 0.2 and 20 um:
          I  = INT(W/0.2)
          Fr = MOD(W, 0.2)/0.2
          Alpha1 = W2(Fr)*Alpha01(I + 2) - W1(Fr)*Alpha01(I + 1)
     +           + W0(Fr)*Alpha01(I)     - WM(Fr)*Alpha01(I - 1)
          Beta1  = W2(Fr)*Beta01  (I + 2) - W1(Fr)*Beta01  (I + 1)
     +           + W0(Fr)*Beta01  (I)     - WM(Fr)*Beta01  (I - 1)
      END IF

      IF (19.8 .LT. W .AND. W .LT. 190.) THEN
C     use Lagrange 4 point interpolation on Block 02 data which
C     are at 10 um spacing between 10 and 200 um:
          I  = INT(W/10.)
          Fr = MOD(W, 10.)/10.
          Alpha1 = W2(Fr)*Alpha02(I + 2) - W1(Fr)*Alpha02(I + 1)
     +           + W0(Fr)*Alpha02(I)     - WM(Fr)*Alpha02(I - 1)
          Beta1  = W2(Fr)*Beta02  (I + 2) - W1(Fr)*Beta02  (I + 1)
     +           + W0(Fr)*Beta02  (I)     - WM(Fr)*Beta02  (I - 1)
      END IF

      IF  (190. .LE. W) THEN
C     print error message and return:
          RHO = 0.
          WRITE (6, 1000) V
          RETURN
      END IF

      G = Alpha1**2 - Beta1**2 - SIN(Omega)**2
      H = 4*(Alpha1**2)*(Beta1**2)
      P = SQRT(0.5*(-G + SQRT(H + G**2)))
      Q = SQRT(0.5*(+G + SQRT(H + G**2)))

C     Stratton, Equation (74), p. 505:
      C  = (Q - COS(Omega))**2 + P**2
      D  = (Q + COS(Omega))**2 + P**2
      Rp = C/D

C     Stratton, Equation (77), p. 506:
      E  = ((Alpha1**2 - Beta1**2)*COS(Omega) - Q)**2
      F  = ((Alpha1**2 - Beta1**2)*COS(Omega) + Q)**2
      T  = (2*Alpha1*Beta1*COS(Omega) - P)**2
      U  = (2*Alpha1*Beta1*COS(Omega) + P)**2
      Rs = (E + T)/(F + U)

      Rho = (Rp + Rs)/2.

      RETURN
 1000 FORMAT (' ***** WARNING - INPUT FREQUENCY = ', 1PG12.5, 'CM-1',
     +       /, ' OUTSIDE VALID RANGE OF 52.63 TO 25,000 CM-1  ******',/)
      END

      BLOCK DATA SeaData
      COMMON /SeaIndex/ Alpha01(100), Alpha02(20),
     +                  Beta01 (100), Beta02 (20)
```

```
************************************************************************
*                                                                      *
*    These data for the optical index of water have been taken from    *
*    the literature.  From 0.2 to 2 microns (blocks 01 up to second    *
*    entry of row B) and from 10 to 200 microns (blocks 02) the data   *
*    are from G. M. Hale and M. R. Querry, "Optical Constants of Water*
*    in the 200-nm to 200-um Wavelength Region," Appl. Opt. 3, 555     *
*    (1973).  These data are for pure water.                           *
*                                                                      *
*    From 2.2 to 20 microns (blocks 01 from the third entry of row B   *
*    to the end) the data are from M. R. Querry, W. E. Holland, R. C. *
*    Waring, L. M. Earls, and M. D. Querry, "Relative Reflectance and *
*    Complex Refractive Index in the Infrared for Saline Environmental*
*    Waters," J. Geophys. Res. 82, 1425 (1977), Table 3, Pacific       *
*    Ocean columns.  These data are for salt water.                    *
*                                                                      *
************************************************************************

C     Real part of the index of sea water from 0.2 to 20 microns in
C     steps of 0.2 microns:
      DATA Alpha01  /
     A        1.396, 1.339, 1.332, 1.329, 1.327, 1.324, 1.321, 1.317,
     B        1.312, 1.306, 1.303, 1.287, 1.251, 1.151, 1.384, 1.479,
     C        1.421, 1.388, 1.368, 1.355, 1.347, 1.339, 1.335, 1.335,
     D        1.332, 1.324, 1.312, 1.296, 1.268, 1.271, 1.371, 1.353,
     E        1.340, 1.330, 1.324, 1.319, 1.314, 1.307, 1.302, 1.297,
     F        1.291, 1.286, 1.279, 1.272, 1.268, 1.264, 1.258, 1.249,
     G        1.240, 1.229, 1.218, 1.204, 1.190, 1.177, 1.165, 1.151,
     H        1.140, 1.132, 1.124, 1.119, 1.121, 1.126, 1.134, 1.142,
     I        1.152, 1.164, 1.177, 1.189, 1.201, 1.212, 1.224, 1.234,
     J        1.242, 1.253, 1.261, 1.273, 1.284, 1.296, 1.309, 1.320,
     K        1.331, 1.339, 1.349, 1.358, 1.366, 1.379, 1.390, 1.399,
     L        1.408, 1.417, 1.426, 1.435, 1.443, 1.450, 1.458, 1.464,
     M        1.470, 1.474, 1.477, 1.480  /

C     Real part of the index of sea water from 10 to 200 microns in
C     steps of 10 microns:
      DATA Alpha02  /
     A        1.218, 1.480, 1.551, 1.519, 1.587, 1.703, 1.821, 1.886,
     B        1.924, 1.957, 1.966, 2.004, 2.036, 2.056, 2.069, 2.081,
     C        2.094, 2.107, 2.119, 2.130  /

C     Imaginary part of the index of sea water from 0.2 to 20 microns in
C     steps of 0.2 microns:
      DATA Beta01  /
     A        0.000, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000,
     B        0.000, 0.001, 0.000, 0.001, 0.003, 0.114, 0.263, 0.085,
     C        0.018, 0.005, 0.003, 0.004, 0.007, 0.011, 0.016, 0.016,
     D        0.013, 0.011, 0.010, 0.013, 0.032, 0.108, 0.087, 0.044,
     E        0.035, 0.033, 0.032, 0.031, 0.031, 0.032, 0.032, 0.033,
     F        0.034, 0.036, 0.038, 0.041, 0.044, 0.046, 0.046, 0.047,
     G        0.048, 0.050, 0.054, 0.060, 0.068, 0.079, 0.091, 0.107,
     H        0.125, 0.145, 0.166, 0.191, 0.216, 0.239, 0.260, 0.279,
     I        0.297, 0.313, 0.326, 0.338, 0.347, 0.357, 0.363, 0.371,
     J        0.377, 0.385, 0.393, 0.401, 0.407, 0.413, 0.417, 0.418,
     K        0.420, 0.422, 0.424, 0.427, 0.430, 0.432, 0.432, 0.432,
     L        0.431, 0.430, 0.429, 0.427, 0.425, 0.423, 0.420, 0.416,
```

```
     M       0.414, 0.410, 0.406, 0.393  /

C     Imaginary part of the index of sea water from 10 to 200 microns in
C     steps of 10 microns:
      DATA Beta02  /
     A       0.051, 0.393, 0.328, 0.385, 0.514, 0.587, 0.576, 0.547,
     B       0.536, 0.532, 0.531, 0.526, 0.514, 0.500, 0.495, 0.496,
     C       0.497, 0.499, 0.501, 0.504  /

      END
```

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

November 1995

3. REPORT TYPE AND DATES COVERED

Final: September 1994

4. TITLE AND SUBTITLE

SeaRad, A SEA RADIANCE PREDICTION CODE

5. FUNDING NUMBERS

PE: 0602435N
AN: DN302215

6. AUTHOR(S)

C. R. Zeisse

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
800 North Quincy Street
Arlington, VA 22217–5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

TR 1702

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Sea radiance is modeled by combining the methods of geometrical optics with the Cox-Munk statistical description of ocean capillary waves. The model is incorporated into the atmospheric transmittance/radiance code MODTRAN2 to provide numerical sea radiance predictions.

In this model each individual capillary wave facet is allowed to reflect the sky or sun and emit thermal radiation. The total radiance from the sea is obtained by applying the proper statistical weight to each facet and integrating it over all facets within the observer's field-of-view.

The modified MODTRAN2 code, called *SeaRad*, calculates sea radiance for any viewing geometry in the spectral range from 52.63 cm^{-1} to 25000 cm^{-1}. Typical execution speeds are approximately 10 s per pixel on a Pentium/90 MHz personal computer. Preliminary comparisons show that *SeaRad* agrees to within several degrees Celsius (°C) with actual sea radiance measurements in the mid-wave and long-wave infrared bands.

14. SUBJECT TERMS

sea radiance
FORTRAN source code
ocean capillary wave facet

15. NUMBER OF PAGES

85

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

21a. NAME OF RESPONSIBLE INDIVIDUAL	21b. TELEPHONE *(include Area Code)*	21c. OFFICE SYMBOL
C. R. Zeisse	(619) 553–3602	Code 543

INITIAL DISTRIBUTION

Code 0012	Patent Counsel	(1)
Code 0271	Archive/Stock	(6)
Code 0274	Library	(2)
Code 54	J. H. Richter	(1)
Code 54	N. Vorce	(1)
Code 543	R. A. Paulus	(1)
Code 543	S. G. Gathman	(1)
Code 543	D. R. Jensen	(1)
Code 543	K. M. Littfin	(1)
Code 543	C. P. McGrath	(1)
Code 543	K. D. Anderson	(1)
Code 543	C. P. Hattan	(1)
Code 543	G. E. Linden	(1)
Code 543	H. V. Hitney	(1)
Code 543	L. R. Hitney	(1)
Code 543	A. E. Barrios	(1)
Code 543	W. L. Patterson	(1)
Code 543	L. T. Rogers	(1)
Code 543	C. R. Zeisse	(50)
Code 555	S. A. Pappert	(1)
Code 555	M. N. McLandrich	(1)
Code 555	D. P. Mullin	(1)
Code 555	C. A. Hewett	(1)
Code 754	D. Forbes	(1)
Code 754	D. Law	(1)
Code 754	R. Carlson	(1)
Code 754	I. Bendall	(1)
Code 754	E. Floren	(1)
Code 754	G. Gilbert	(1)
Code 754	R. Tong	(1)
Code 754	T. Metcalf	(1)
Code 844	A. King	(1)

Defense Technical Information Center
Fort Belvoir, VA 22060–6218 (4)

Center for Naval Analyses
Alexandria, VA 22302–0268

GIDEP Operations Center
Corona, CA 91718–8000

Naval Surface Warfare Center
Silver Spring, MD 20903–5640

Naval Research Laboratory, Detachment
Monterey, CA 93943–5006

NCCOSC Washington Liaison Office
Washington, DC 20363–5100

Navy Acquisition, Research and Development
Information Center (NARDIC)
Arlington, VA 22244–5114

Naval Research Laboratory
Washington, DC 20375 (3)

Naval Surface Warfare Center
Bethesda, MD 20084–5000

Naval Air Warfare Center,
Weapons Division
Point Mugu, CA 93042–5001 (3)

Naval Postgraduate School
Monterey, CA 93943–5100 (10)

ARETE' Associates
Sherman Oaks, CA 91413 (3)

Photon Research Associates, Inc.
La Jolla, CA 92037–1020

Viz Ability, Inc.
Corvallis, OR 97330

Michigan Technical University
Houghton, MI 49931–1295 (4)

University of California, San Diego
La Jolla, CA 92093–0230 (2)

Office of Naval Research
Arlington, VA 22217–5660 (4)

Aerodyne Research, Inc.
Billerica, MA 01821–3976 (2)

Science & Technology Corporation
Hampton, VA 23666–1340

Jet Propulsion Laboratory
Pasadena, CA 91109–8099

Texas A&M University
College Station, TX 77843

FOREIGN

Physics & Electronics Laboratory TNO
The Netherlands (4)

Physics Department UMIST
United Kingdom

European Centre for Medium Range Weather Forcasts
United Kingdon

Defense Research Establishment Valcartier
Quebec GOA 1R0 Canada (3)